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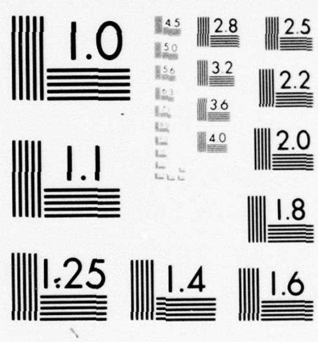

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CONDUCTIVE FLOORING FOR MUNITIONS FACILITIES

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TECHNICAL REPORT
CIVIL ENGINEERING LABORATORY

Naval Construction Battalion Center, Port Hueneme, California 93043

By Peter J. Hearst, Ph D

June 1979

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Information is presented for use as guidelines in the selection of conductive flooring for munitions facilities. Available conductive floorings are described in the categories of concretes, organic composition toppings, coatings, coverings, and metal sheetings. Problems with conductive floorings and performance experiences at munitions facilities are discussed. Reconditioning, grounding, electrical resistance limits, and resistance measurement of conductive flooring also are discussed.

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INTRODUCTION

Static electricity, which can set off sensitive explosives, is a potential hazard at ammunition plants and other ordnance facilities. Explosions continue to occur, and some of these may have been caused by static electricity. Conductive flooring, which drains away and prevents the buildup of static electricity, is extensively used at munitions facilities. Conductive flooring is also used in hospital operating rooms to prevent static charges that might set off explosions of inflammable anesthetics.

There are many continuing problems with conductive flooring for munitions facilities. These include the loss of conductivity in older floors, physical deterioration of the floors, incorrectly installed floors, and substitution of less expensive but less effective methods or materials.

Many conductive flooring materials are available. Their properties may make them suitable for some areas but not for others. Very few guidelines are available for the selection of conductive flooring for any particular use. Many floorings used at munitions facilities are not covered by any specifications other than the broad requirements of safety manuals. Therefore, persons choosing the floorings must rely on their knowledge of the field and good judgment.

The purpose of this report is to provide additional information on which the selection of conductive floorings can be based. The suitability of various conductive floorings for various munitions operations is discussed. Available conductive floorings are described, and performance experiences at munitions facilities are reviewed. Some special problems related to conductive flooring are also discussed.

BACKGROUND

The Army safety manual (Ref 1) states that "conductive floors must be of nonsparking material such as lead, conductive rubber, or conductive flooring composition" and mentions some general requirements for conductive flooring. It does not discuss individual types, except that "lead or other soft flooring material" should be used where initiating explosives are handled. The Navy safety manual (Ref 2) states that "conductive floors may be made of lead, conductive rubber or plastic, conductive masonry material, or conductive composition material." It lists some properties of the flooring but contains no further discussion of specific types of floors.

The Army has a guide specification for conductive sparkproof industrial resinous flooring (Ref 3), which covers epoxy, polyester, and latex-modified concrete (LMC) flooring systems.* Similar polyester floorings or LMC floorings can be procured by use of the applicable military specifications (Ref 4 or 5, respectively) in combination with the requirements of the National Fire Protection Association (NFPA) (Ref 6). The Navy has one current specification for conductive flooring - a type specification for metallic finish concrete (Ref 7). Neither this type specification nor the Army guide specification indicates where the particular flooring should be used.

The Civil Engineering Laboratory (CEL) has previously investigated conductive flooring for ordnance facilities and hospitals. Problems with conductive flooring at Navy and other facilities were studied, and conductive flooring materials available at that time were examined (Ref 8). There were considerable discrepancies in the manner of measuring electrical resistances of conductive floorings at Army and Navy munitions facilities and at hospitals; this problem was addressed in another CEL report (Ref 9).

A more detailed CEL study of experiences and problems with conductive floorings at Naval ordnance facilities has been documented (Ref 10). This study was further broadened to include Army ammunition plants and arsenals. Thus, many Army ammunition plants, Army arsenals, and Naval ordnance facilities that use conductive flooring were visited, and conferences were held with personnel involved in various capacities with these floorings. Other Army, Navy, and commercial munitions facilities were contacted by telephone. Conferences were held also with manufacturers of conductive flooring and with manufacturers of raw materials that are used in conductive flooring.

An investigation of several conductive floor coatings had been made at the Naval Weapons Center (Ref 11). More recently the Army became interested in less expensive substitutes for lead flooring, and properties of various conductive flooring materials were determined at the Construction Engineering Research Laboratory (Ref 12-14). Properties of plastic conductive flooring and methods of testing such flooring were discussed in a publication of the Plastics Technical Evaluation Center (Ref 15). The results of these studies and conferences with the investigators were of help in the present study.**

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*This guide specification requires electrical resistances between 25,000 and 1,000,000 ohms, which are the limits normally required for hospitals; therefore, the floorings may exceed the 250,000-ohm limit of the Army safety manual (Ref 1).

**On the basis of a draft of the present report, a supplementary report has been issued by the Plastics Technical Evaluation Center that provides additional information on flooring composition and properties and further discusses performances that might be expected on the basis of the flooring compositions, including chemical resistance and compatibility with explosives: PLASTEC Note N34, Review of available conductive flooring materials for munitions facilities, by John Nardone and Arthur Reddy, Dover, N.J., Nov 1978.

SUITABILITY OF CONDUCTIVE FLOORINGS FOR MUNITIONS OPERATIONS

A matrix showing floorings suitable for various ordnance operations, ranked in order of preference, would be desirable to have. But the preparation would be no simple task. To prepare such a matrix, one would need to know the requirements of the various munitions operations as they apply to conductive flooring. One would also need to determine the properties of various conductive floorings and determine how they fulfill the requirements of the various operations.

The flooring requirements of munitions operations presumably could be obtained from various Army ammunition plants and other facilities visited. The properties of conductive floorings presumably could be obtained on an experimental basis either from laboratory experiments or from test results reported by the various conductive flooring manufacturers. But there are no laboratory tests that reliably predict such performance, and test results supplied by manufacturers may be biased or obtained under inadequately described conditions. The properties of the conductive flooring could also be obtained in a less controlled manner, but in some cases perhaps a more meaningful manner, by evaluating the performance experiences at Army and Navy munitions facilities.

Requirements for Conductive Flooring

Conductive munitions flooring must have specialized properties required by the applicable Army safety regulations (Ref 1), by Navy safety regulations (Ref 2), or by commonly accepted safety practices. Included besides conductivity are spark resistance, compatibility with explosives, imperviousness, and in some cases, resilience. Flooring at munitions facilities must also have many properties that are unrelated to the explosives and other materials that are handled, but that are required because of the industrial operations that take place. These properties include resistance to various loads and to abrasion, slip resistance, adhesion to the subfloor, and resistance to water, solvents, and chemicals. Some of these properties are briefly discussed below, and most are discussed in more detail in Appendix A, together with related test methods.

The conductivity of the flooring must be sufficiently high to adequately discharge any static electricity from a person or equipment moving on the floor. The Army safety regulations require a maximum resistance of 250,000 ohms from any point on the floor to electrical ground, and they require no minimum resistance. The Navy safety regulations require a maximum resistance of one million ohms and also require a minimum resistance of 5,000 or 10,000 ohms where there is electrical service. Thus, some commonly used floorings with high conductivity, such as lead, do not meet Navy regulations if the area has electrical service. Other floorings of higher resistance, such as vinyl tile, may meet Navy regulations but not Army requirements.

The spark resistance must be such that the flooring will not spark when struck with hardened steel tools. Some floors are made sparkproof by the application of suitable topcoats, and if such topcoats are worn off as the floorings are used, they will no longer be sparkproof.

Although not mentioned in Army or Navy safety regulations, it is important that the flooring be compatible with the explosives that are processed, so that explosives spilled on the floor will not, by virtue of their reaction with flooring components, become more sensitive or dangerous to handle. The flooring must be impervious and free of cracks or open seams to prevent any buildup of spilled explosives. A need for resilience of some floorings is implied by the Army requirement that floors of lead or other soft material be used where initiating explosives are handled.

Requirements of Munitions Operations

Information about various munitions operations was obtained during visits to Army ammunition plants and to other Army and Navy facilities. A form modified from one contained in Reference 15 was used to collect this information. The first page requested information about the products manufactured and about temperature and humidity conditions. It also requested a list of different types of operations that place different requirements on the conductive flooring. For each of these operations, an additional page was used to list the loading requirements of the floors, including static loads, dynamic traffic, and foot traffic. The various materials that are handled were listed, including cleaning agents and solvents. There was also a space for special requirements and remarks.

The information so obtained is summarized in Table 1. The operations listed are those for which information was obtained; however, these are typical operations and do not include all the operations that are performed. Several related operations may place similar requirements on the flooring and, therefore, no separate requirements were provided. Some operations are listed twice because differing information on the requirements was provided by different ammunition plants. Back-line operations with initiating explosives include screening, weighing, blending, etc., of the loose explosives. Front-line operations include the loading of these explosives into metal cups.

Under floor loading, the most severe loading encountered is listed. This is normally the dynamic loading. Static loading is usually not a problem, because heavy static loads are usually placed on the subfloor rather than on the conductive flooring. Where the information is available, the loading is expressed in pounds per inch of wheel width, and the diameter and tread surface of the wheels are given. It is difficult to give such loadings in pounds per square inch because the effective contact area is not known. Thus, steel wheels on a very hard floor will have a very narrow band of contact, whereas the same wheels on a resilient floor will have a much wider contact area; and softer treads will have a wider contact area than hard treads.

Water, usually cold but often hot, is the most common cleaning agent used. Solvents are sometimes used for cleanup, but exposure to solvents is primarily due to spillage. Chemicals that contact the conductive flooring are primarily kill solutions used to destroy residual explosives. These may include ceric ammonium nitrate, ammonium acetate, potassium dichromate, nitric acid, acetic acid, sodium nitrite, sodium sulfide, sodium thiosulfate, sodium hydroxide, or ferric chloride (see Section 27-8 of Reference 1).

The special requirements most often listed are imperviousness and resilience. At one ammunition plant, the decision regarding which flooring to use depends entirely on whether nitroglycerin is handled: if so, lead flooring is used, which is impervious; if not, a latex-modified concrete is used.*

The conditions listed in Table 1 are sometimes not those that contribute most to flooring problems. For instance, one activity indicates that its flooring failures are chiefly caused by shut-down or layaway periods. This is primarily because of the temperature changes that take place. Although an attempt is made to maintain temperatures above about 40°F, temperatures may get considerably lower during cold weather. Layaway temperatures as low as 10°F or 20°F are reported by some ammunition plants; however, the flooring might not reach these low temperatures.

Experimental Determination of Flooring Properties

When considering experimental measurements of the properties of conductive flooring to determine their suitability in meeting the requirements of various munition operations, as listed in Table 1, a number of problems became evident. The major problem is that the requirements often cannot be related to single, measurable properties. Thus, the ability to withstand dynamic traffic depends on several properties, including compressive and flexural strength, and resistance to impact, indentation, and abrasion. Another problem is that different methods of determining a single property often cannot be correlated with each other.

A further problem is that measured properties may not correlate with performance. Thus, no correlation has been established between the abrasion resistance of flooring and the performance under foot traffic. Similarly, it has been claimed that measurements with slip meters do not give good comparative values for the slip resistance of floorings. In the measurement of slip resistance, there is the additional problem that some floorings are typically applied with a slip-resistant finish, but when the surface roughness wears off, such floorings become more slippery.

For determining the effects of dynamic loading of munitions operations on conductive floorings, a test for resistance to rolling load might give the best comparison. The results of such a test could depend on the variables that were utilized: hardness of wheels, size of wheels, tread of wheels, load placed on wheels, and speed of travel. The comparative performance of two floors also could be different if steel wheels with heavy loads are used than if softer wheels with lighter loads are used.

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*When the latter flooring was used in a drying room containing nitroglycerin vapors, an explosion occurred from the vapors that had been absorbed by the flooring.

Table 1. Conductive Flooring Requirements of Munitions Operations

Operation	Loading[a]	Cleanup (or Contact with Chemicals)[b]	Special Requirements	Reference
Nitroglycerine (Various Operations)	c	c	impervious	16
Initiating Explosives (Back Line)	foot traffic	water, solvents	resilient, impervious	17
Initiating Explosives (Back Line)	125 lb/in., 8-in. hard rubber	steam	resilient	18
Detonator Loading (Front Line)	foot traffic	water, solvents (oil)	resilient	17
Detonator Loading (Front Line)	125-lb buggy	warm water	–	18
Primer Manufacturing	375 lb/in., 8-in. hard rubber	water, steam, acid, hypochlorite	–	19
Igniter Loading	135 lb/in., 4-in. brass	steam	–	20
Propellant Loading	135 lb/in., 4-in. brass	steam	–	20
Propellant Loading	110-lb drum, rubber	warm water	–	18
Small Arms Loading	525 lb/in., 12-in. steel	hot water, steam, detergent	–	19
Pyrotechnics (Various Operations)	20,000-lb forklift[c]	cold water (methylene chloride)[c]	–	21
Melt-Pour (High Explosives)	600 lb/in., 8-in. hard rubber	hot water	smooth, level	22
Drilling (High Explosives)	600 lb/in., 8-in. hard rubber	hot water	–	22
Pelleting (High Explosives)	foot traffic	hot water (acetone)	–	22
Extrusion (High Explosives)	foot traffic	hot water (petroleum solvent)	–	22
Explosives Loading	1,400 lb/in., 8-in. rubber	steam (methylene chloride, trichloroethane)	–	23
Weapons Assembly	420 lb/in., 6-in. rubber	water	dust free	23
Test of Electro Explosive Devices	light foot traffic	water	resilient	23

[a]Expressed where possible as: pounds per inch of wheel width, diameter and tread surface of wheel.

[b]Chemicals in parentheses unintentionally contact the flooring; kill solutions not shown may also be used.

[c]Varies for different operations.

For determining the effects of cleaning agents (including cold and hot water), chemicals, and solvents, exposure of these materials to the flooring surface and visual observation of any effects might give suitable information. To determine the effects of many cleaning agents, chemicals, and solvents on many available flooring materials would require a very large number of experiments. Some information on chemical resistance is available from most of the flooring manufacturers. The effects of solvents, explosive mixtures, or chemicals are often studied at Army or Navy munitions facilities when it is desired to obtain information about the probable performance of a prospective flooring in contact with the specific materials handled at the facilities.

An experimental approach to measure all the properties of all available conductive floorings that would determine their suitabilities for all typical munitions operations would require a large test program, even if information supplied by manufacturers could be incorporated. Furthermore, the results would likely be indicators of possible performance rather than determinations of probable performance. It was, therefore, considered more advantageous to obtain further information on performance experiences from Army facilties and other facilities and to obtain additional applicable information from flooring manufacturers.

A few experiments were performed. These were related to flooring resilience and to electrical resistance measurements. The former are described here, and the latter are described in a section on resistance measurements.

The rebound of a plunger or pendulum has been used as a measure of resilience of rubbery materials (Ref 24). However, it is questionable whether this test is a useful measure of the resilience of conductive flooring. A highly resilient floor will absorb much of the energy of collision of a falling object. Much of this absorbed energy is returned elastically to the falling object to produce the rebound. But energy can be returned by an elastic rubbery material or even better, by a steel or glass surface. The measured rebound would not indicate whether the energy had been absorbed relatively slowly with a cushioning effect and then released again or whether there was no cushioning effect. Energy absorbed through permanent deformation of the floor would add to a feeling of resilience but would not contribute to the rebound.

A simplified rebound test was devised and performed with conductive flooring samples supplied by manufacturers. A small steel ball was dropped on the flooring samples through a 100-cm-long glass tube, and the height of the rebound was measured. The glass tube had a 10 mm inside diameter and was positioned about 3 mm above the sample to allow free flow of air. The steel ball weighed 3.5 gm and measured 9.5 mm in diameter.

The results of the rebound test were inconclusive. The resilient floor coverings gave rebounds from about 16 to 22%, whereas thick, flexible neoprene gave 14% and steel plate 36%. A metallic finish concrete also gave a 14% rebound, which may have been influenced by the organic curing layer on the surface of the flooring. Two latex-modified concretes with organic topcoats gave values of about 9%. In some cases, permanent indentations affected the results, and in other cases the permanent depressions were difficult to detect because of the surface texture or the coloring of the samples.

Army and Navy Experiences With Conductive Flooring

Performance information on conductive flooring was collected from Army and Navy facilities, using a form modified from that contained in Reference 8, in the following six categories: flooring surface, including type and actual product used; usage, including dates, type, and severity; electrical performance, including resistance values and test methods; structural performance; construction details; and maintenance, including cleaning, conductivity restoration, and structural repairs.

It was often difficult to obtain a significant portion of the desired information for the various conductive floors at different facilities. Sometimes the specification under which a floor was installed was available, but no information was available to indicate what product was actually installed. Sometimes apparently knowledgeable individuals had differing opinions about the specific flooring that was used, and sometimes their opinions differed from those of the flooring manufacturers.

Little useful information could be obtained about changes of conductivity with age of the flooring. The electrical resistance information was generally difficult to obtain, and the methods and values reported were sometimes not clear. At most Army facilities and some Navy facilities, brushless shaving cream or other contact agents were used, which resulted in much lower resistance values than otherwise would have been obtained. No information was available about the spark resistance of the floorings. Spark resistance is usually determined after the new flooring has been installed, but is not verified after the flooring has been placed in service. Also, the spark-resistant surface layer may have been worn off of many existing floors without having been detected. Information on the use and loading of the floors generally could be obtained only in very qualitative terms.

The information gathered does not give the measurable performance comparisons that might be expected from controlled laboratory or field studies. The floors were installed at different times with different techniques and were used under different conditions. However, a large amount of information was obtained and is discussed in detail under "Performance of Conductive Flooring." Many of the problems encountered in these field experiences would not have been predicted from small-scale laboratory experiments.

PERFORMANCE OF CONDUCTIVE FLOORING

A variety of conductive floorings are available. These were divided into five categories and various types which are discussed separately below. The description of the available floorings in each type is followed by a discussion of performance experiences.

Several sources of information were used to identify currently available conductive flooring materials. The largest listing of conductive flooring manufacturers is given in Best's Safety Directory (Ref 25), but this source was found to be inaccurate inasmuch as a majority of the companies listed did not offer conductive flooring or did not reply to inquiries. Underwriter's Laboratories (Ref 26) and Sweet's Industrial Construction and Renovation File (Ref 27) list many companies and products. But these lists are not complete because the manufacturers must pay to be listed, and some floorings that are listed are no longer manufactured. The National Terrazzo and Mosaic Association has guide specifications for conductive floorings that are manufactured by member companies (Ref 28). A few of the floorings listed in the tables of this report were not listed in any of these publications but were in use or considered for use by various munitions facilities.

The companies listed in the tables have trade names and literature for their flooring materials and apparently have had considerable experience in providing conductive flooring. Besides these companies, there are other suppliers that offer to modify existing products, such as epoxy toppings, to make them conductive.

In the tables that follow are given the names of the manufacturers of conductive flooring materials, the trade names of their products, the type of binder, vehicle, or material that is used and the typical thickness of some of the floorings. The actual compositions of the floorings are trade secrets, but the general composition information listed was provided by the manufacturers.

The performances of the various floorings, as discussed in this report, are based on the information received from the Army and Navy installations contacted. They represent the author's best judgment on the basis of available information, and are not intended as predictions of future performance of products that might be manufactured differently, installed differently, or used differently.

The installation of the conductive flooring may be one of the most important factors in its performance. For example, metallic hardeners must be dusted onto newly placed concrete at the proper time and not worked in excessively; floor coverings must be brought to the temperature of the subfloor and must be bonded with the proper adhesive at the proper degree of cure; concrete subflooring surfaces must be properly prepared; etc. Thus, while various floorings could probably serve an intended purpose, they are often chosen on the basis of the availability of an experienced applicator. The quality of workmanship in the application of the flooring may affect the bonding of the flooring to the sub-floor, the bonding of various layers of the flooring to each other, the integrity of the body of the flooring, and the slipperiness of the surface.

Concretes

Conductive concrete floors were installed during World War II at many munitions facilities that are still operational. The conductivity of some of these floors may have been provided by dispersing 2 to 3% of carbon black in the mix. The conductive concretes now installed are basically of two types. The type primarily used is metallic finish concrete that has conductive carbon in the hardened surface. The other is oxychloride concrete that is conductive throughout the matrix because of salts that are present.

Metallic Finish Concretes. Conductive metallic finish concretes have also been called conductive metallic toppings, metallic aggregate finishes, or metallic monolithic concretes. They are often called "masterplate floors" as a generic term, because DPS* Masterplate is the product most often used.

Conductive metallic finish concrete is the hardest of the conductive floorings (except for metallic aggregate topping), and is the most widely used conductive flooring in areas of heavy loading. Most Army and Navy munitions facilities have used such floors for many years, and many munitions facilities continue to install this type of flooring despite the availability of newer types of conductive flooring. This type of flooring is also used at many Navy facilities where ammunition is handled or stored or at test facilities.

The conductive hardeners used to make metallic finish concrete are supplied by the manufacturers shown in Table 2. The metallic surfacing material consists not only of iron, which in addition to cement is the chief ingredient of most metallic concrete hardeners, but also contains carbon black and other admixtures. In the finished floor, the metallic hardener is contained primarily in the upper 1/8 inch of the flooring, as illustrated in Figure 1.

It has been claimed that there are only two primary manufacturers of this type of material, and several of the companies listed in Table 2 do obtain their hardeners from other sources. The manufacturers listed provide only the hardeners and possibly technical information and guidance; they do not generally provide the other materials required for the concrete flooring, nor do they install the flooring.

A discussion of the installation of metallic finish concrete is contained in Appendix B.

Current Navy regulations require a minimum resistance for conductive flooring of 5,000 ohms where 110-volt electrical service is supplied and 10,000 ohms where higher voltage electrical service is supplied (Ref 2). Master Builders will not supply its DPS Masterplate where such minimum resistances are specified, because in wet or damp areas even normal concrete can have lower resistances than those specified. Other manufacturers make no such reservations. However, in prior CEL investigations (Ref 29, 30), flooring made with hardeners supplied by four other companies (of which only Ferrolith H is still marketed) required up to almost 1 year to reach a resistance of 10,000 ohms. DPS Masterplate flooring never reached this resistance in 2-1/2 years, during which time the resistances of the other floors increased to a range of about 50,000 to 200,000 ohms.

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*DPS stands for "designed and packaged for safety."

Table 2. Conductive Concretes

Product	Manufacturer
Metallic Finish Concretes	
DPS Masterplate	Master Builders Div of Martin Marietta Corp Lee at Mayfield Cleveland, OH 44118
MAXIRON Spark-Resistant	Maximent Division SET Products, Inc 822 Delta Ave Cincinnati, OH 45226
Metalplate SD	National Pulverized Metals Co Div of Metalcrete Corp 50 West 60th St Chicago, IL 60621
LITHOCHROME Spark-Resistant Surface Hardener	L. M. Scofield Co 5511 East Slauson Ave Los Angeles, CA 90040
Ferrolith H Sparkproof	Sonneborn Building Products Div of Contech, Inc 7711 Computer Ave Minneapolis, MN 55435
Metallic Aggregate Concrete	
Anvil Top	Master Builders Div of Martin Marietta Corp Lee at Mayfield Cleveland, OH 44118
Oxychloride Concretes	
Hubbelite 300	Hubbelite Div of Allegheny Installations 3600 William Flynn Highway Allison Park, PA 15101
Kompolite Sparkproof Conductive Flooring	Marbeloid Corp 2515 Newbold Ave Bronx, NY 10462

Figure 1. Sample of metallic finish concrete (DPS Masterplate).

Master Builders also manufactures the ingredients for Anvil Top, which is a metallic aggregate topping. This topping, which consists predominately of iron and is one-half to one inch thick, is intended for areas of very heavy wear, but since it is conductive, it also has been used as a conductive flooring.

Most of the activities contacted have had satisfactory performances with metallic finish concrete floors. Many also have had problems. These problems included cracking of the floors, lifting of the topping, rusting where water remained standing, loss of conductivity in older floors, and wearing of older floors. Some of these problems may have been related more to the installation procedures than to the products used. For instance, at one activity, the installation of metallic finish concrete floors was no longer considered a problem and could easily be contracted out; but a few years later, cracks developed in several of the new installations (Ref 31). At another activity, an 8-inch slab made with an unidentified hardener developed cracks clear through the slab, and the same thing happened when the slab was replaced (Ref 32). However, this problem probably was unrelated to the metallic finish. Another flooring that was poorly protected and partially exposed to the desert sun developed large shrinkage cracks during curing, but a good flooring resulted from the same type of flooring when it was completely covered with a vinyl blanket while curing (Ref 33).

Little comparative information is available for the various conductive hardeners listed in Table 2. The identities of the hardeners used for specific installations were generally not known. Where the identity was known, DPS Masterplate was the one most often used, and the number of installations with other known hardeners was not sufficient to allow any conclusions to be drawn about comparative performance. Some of the floors that are called "masterplate floors" may have been constructed with an older Masterplate, before 1955 when DPS Masterplate became available, and some may have been constructed with hardeners from other suppliers.

Although the metallic finish concrete floors are generally installed by contractors, one activity has installed its own DPS Masterplate flooring for over 20 years; it is also the only conductive flooring used at that activity (Ref 34). The flooring is subjected to considerable cold water washing, and many areas are in good condition except for minor cracks. Some of the older flooring looks somewhat worn, but it has good conductivity.* Some of the flooring has been damaged by perchlorate. Damage by strong oxidizing agents of metallic finish concrete made with an unknown hardener has been reported by another activity (Ref 21). DPS Masterplate flooring is used with much water washing at another activity, but the floor remains black and has only a few rusty spots; an older floor of unknown composition was less black and more rusty (Ref 35).

A flooring prepared with Metalplate SD had a dark, coppery color, felt like a soft metal, and rubbed off easily (Ref 36). It also sparked when struck with a file, but the lack of spark resistance could have been caused by faulty installation. A flooring made with Ferrolith H, which otherwise performed well for 7 years and developed minimum cracking, was very slick and a black material, presumably carbon, was easily rubbed off the floor (Ref 34). Another Ferrolith H flooring performed well for a similar period of time at another activity (Ref 36), but loss of adhesion was indicated by hollow sounds produced under a heavy chain; it also was slightly rusty where water had puddled. However, this flooring had replaced a DPS Masterplate flooring that had lost adhesion at the same location. No performance information was available for flooring made with the MAXIRON or the LITHOCHROME hardeners.

The Anvil Top metallic aggregate flooring was used at only one activity where a smooth and unworn surface was required because of heavy loading (Ref 22). Its performance was very good in an area where DPS Masterplate did not stand up as well.

Oxychloride Concretes. Oxychloride cement contains magnesium oxide and magnesium chloride; therefore, oxychloride concretes are moderately conductive without additives. Floorings made with this material are also called oxychloride composition floorings or are sometimes loosely called magnesite floorings. Because conductive carbon does not need to be added, the material can be obtained in various light colors. Oxychloride terrazzo appears more pleasing than the carbon-containing Portland cement terrazzo. These two terrazzos, a few decades ago, were the most widely installed conductive hospital floorings. An American Standards Association specification for oxychloride composition flooring (Ref 37) covers both a troweled finish, primarily for munitions activities, and a terrazzo floor, primarily for hospitals. Oxychloride

*However, this is measured with the aid of brushless shaving cream for better contact.

composition flooring was at one time covered by a Navy type specification (Ref 38). The two proprietary oxychloride compositions listed in Table 2 are intended for munitions activities.

Although claimed to be more wear-resistant than ordinary concrete, the oxychloride flooring is not as durable as the metallic finish concrete. It performs adequately with light loads, but is damaged by heavy loads. The oxychloride flooring may not perform well under frequent wetting, especially if the seal coat is worn off. Its electrical resistance varies with humidity, being higher at lower humidity because of loss of water from the flooring (Ref 39).

At most of the activities visited, the existing oxychloride floors were very old installations. At one activity, the local personnel were skilled in installing and repairing this type of flooring. It appears the Kompolite material is the only conductive flooring material that they are able to install without special training (Ref 40). Some of the older oxychloride floors at this same activity had electrical resistance readings of about 300,000 ohms, even when a contact solution was used. Another activity had extensive areas of oxychloride flooring, some of which had been in service for 36 years (Ref 20). Many areas had been patched, and some areas of heavy usage had been replaced several times with a new Kompolite topping. Some of the floors were very worn in areas subjected to frequent washing with water. Some areas were coated with a black conductive paint that had worn off at the high spots in the flooring. Yet, at another activity, the Kompolite floorings in use for 36 years were still quite serviceable in many areas; however, in recent years these floors had been painted with a black acrylic latex conductive paint to regain their conductivity (Ref 19). At the same activity, a 6-year-old black Hubbelite 300 flooring was in good condition, except for minor cracks, but it had spalled next to a moat where it was frequently washed with dilute nitric acid. Some troubles were encountered with more recent installations of the same flooring. In one case, alligatoring had resulted because of improper application, and at another area, considerable cracking had occurred. These cracks were filled with a black epoxy patching compound.

Organic Composition Toppings

Conductive organic composition toppings are seamless floors that are generally applied over concrete subfloors in thicknesses of about one-quarter inch, depending on the product. Such toppings are listed in Table 3. Some consist of a water-dispersed polymer and a hydraulic cement binder with inert and conductive fillers; others consist of an organic binder with inert and conductive fillers.

Many of these floors are conductive versions of commercial nonconductive floorings available in different colors. The main difference in the formulation is the addition of the conductive carbon, usually acetylene carbon black. Many different carbon blacks are available on the market, but only a few of these have the high conductivity that is required for conductive floorings. If the proper carbon is used, the amount added can be kept so low that it is claimed not to influence the physical properties of the flooring.

Organic composition toppings without marble chips are called industrial floors. Marble chips can be added to the black flooring so that it can be polished to obtain a terrazzo finish. Marble chips of less than 1/4 inch cross section do not reduce the effectiveness of the flooring in disseminating static electricity. Some conductive terrazzo floors are made with granite chips, but these floors are likely to cause sparking when struck by steel tools. Terrazzo floors are usually used in hospitals and only occasionally at munitions facilities; they are listed in Table 3 only as footnotes.

Conductive floor toppings can be installed over moisture barriers, and are usually installed over primers. Most of these toppings have a thicker layer with coarser aggregate followed by a thinner layer with finer aggregate. The floors may be covered with a topcoat or with a sealer.

Many of the toppings listed in Table 3 are products that meet MIL-D-3134 for deck covering materials* (Ref 5) and also satisfy the conductivity requirements of NFPA Standard 56A (Ref 6). MIL-D-3134 lists deck covering materials with exposed marble chips (Type I or terrazzo floors), and uniformly colored coverings without marble chips (Type II or industrial floors). Type I is divided into latex mastic and resin emulsion deck coverings (Class 1), and two-part deck covering materials, such as epoxies (Class 2). The Type II floors include only latex mastic materials that correspond to the Class 1 materials of the Type I floors, but do not include the two-part materials.

One of the toppings listed in Table 3 satisfies the requirements of NFPA 56A and meets MIL-F-52505 requirements for a resinous monolithic floor coating (Ref 4). Because the latter specifies a trowel-applied polyester flooring 1/4 inch thick, this flooring is listed as a topping.

Besides the manufacturers listed in Table 3, there are other firms that offer to supply or formulate conductive floorings that meet the above specifications or the guide specifications of the National Terrazzo and Mosaic Association (Ref 28). Such floorings may also meet the Army guide specifications for conductive sparkproof industrial resinous flooring (Ref 3), and the corresponding terrazzo floors may meet the guide specification for conductive resinous terrazzo flooring (Ref 41). The Army guide specification for conductive industrial flooring covers epoxy, polyester, and latex flooring systems, the last of these being latex-modified concretes. The matrices of these floorings, without chips or fillers, are required to conform to the specifications of the National Terrazzo and Mosaic Association (NTMA) for the corresponding matrices of their terrazzo floorings (in the 1970 edition of Reference 28), and the conductivities of these floorings must meet the requirements of NFPA 56A. The specifications of NTMA for polyester flooring are essentially those of MIL-F-52505, and for latex-modified concrete are essentially those of MIL-D-3134.

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*The word "covering" as used in MIL-D-3134 denotes a topping, rather than a covering, as the terms are used in this report.

Table 3. Conductive Organic Composition Toppings

Product	Typical Thickness (in.)	Manufacturer	Remarks
Latex-Modified Concretes			
Dex-O-Tex No. 303 Conductive Neotex Industrial-38	1/4	Crossfield Products Corp[a] 3000 E. Harcourt St Compton, CA 90221	Neoprene latex; more flexible
Dex-O-Tex Conductive Neotex (Industrial-67 formulation)	1/4	Crossfield Products Corp	Proprietary latex; more firm
Dex-O-Tex Conductive Neotex-367	1/4	Crossfield Products Corp	Proprietary latex; more firm
Dex-O-Tex Conductive HR-321	3/8 - 1/2	Crossfield Products Corp	Acrylic latex; thicker and tougher
Conductive Selbatuf	1/8 - 1/2	Selby, Battersby & Co[b] 5220 Whitby Ave Philadelphia, PA 19143	Acrylic latex
Epoxy Toppings			
Coroline 510	1/8	Ceilcote Co 140 Sheldon Rd Berea, OH 44017	Embedded glass cloth
Dex-O-Tex Conductive Cheminert	1/16 - 1/8	Crossfield Products Corp	Contains aluminum; has aluminum color

continued

Table 3. Continued

Product	Typical Thickness (in.)	Manufacturer	Remarks
Epoxy Toppings (continued)			
Conductive Sparkproof Industrial BC-5245/46 System	1/4	H. B. Fuller Co[c] 315 South Hicks Rd Palatine, IL 60067	
Deco-Rez Conductive Industrial Epoxy Topping No. 115	1/4	General Polymers Corp[d] 3925 Houston Ave Cincinnati, OH 45212	Available as Conductive or Conductive and Nonsparking
Polyester Toppings			
Ceilcrete 2500B and 6400B	1/8	Ceilcote Co	Embedded glass cloth
Deco-Rez Conductive Ceram	1/8 - 1/4	General Polymers Corp	Available as Conductive or Conductive and Nonsparking

[a] Also markets Dex-O-Tex 303 Conductive Terrazzo, a neoprene LMC terrazzo, and Dex-O-Tex P-610 Conductive Terrazzo, a proprietary LMC Terrazzo.

[b] Also markets Conductive Novalite, an acrylic LMC terrazzo.

[c] Also markets Conductive Tufflite, an epoxy terrazzo.

[d] Also markets Deco-Rez Conductive Epoxy or Polyester Terrazzo.

Considerable skill is required to properly install the flooring materials listed in Table 3. Most of the manufacturers of these materials have authorized agents who install the flooring. Generally, they will sell the materials directly to customers only when the latter are properly trained to install the flooring.

Latex-Modified Concretes. Floor toppings that consist primarily of a water-dispersed polymer, a cementitious binder, and aggregate are often called latex-modified concretes (LMC). Such materials also are known as polymer-cement-concretes. Other designations, as noted above for MIL-D-3134, are latex mastic floorings and resin emulsion type floorings.

The inclusion of a polymer in the concrete can increase the resilience and strength of the concrete. By varying the type and proportion of polymer, floors with varying degrees of hardness, flexibility, and toughness can be obtained. For example, experiments conducted at CEL with nonconductive concretes have shown that a dispersion of predominantly poly(vinylidene chloride) added to a concrete mix can raise the strength of the concrete by a factor of seven (Ref 42). This strength is probably not typical of the conductive floorings listed in Table 3. Also, the surface hardness of the LMCs would be much less than that of the metallic finish concretes.

The latex-modified concretes typically consist of a prime coat, a body coat (also called wear coat or grit coat) with aggregate that provides the major thickness, a grout coat with fine aggregate that fills any voids, and a topcoat or sealer. Available LMCs are described in greater detail in Appendix C. These include Conductive Selbatuf that uses an acrylic latex as part of the binder; this is illustrated in Figure 2. Also included are three Dex-O-Tex LMCs: Conductive Neotex Industrial-38, that uses a neoprene latex; Conductive Neotex Industrial-67, that uses a latex of undisclosed composition and is similar to Neotex-367; and Conductive HR-321, that uses an acrylic copolymer latex. These Dex-O-Tex floors can be covered with various topcoats; the Industrial-67 with Cheminert Topcoat is illustrated in Figure 3.

The properties of the LMC floorings are influenced not only by the polymer latices used, but also by the cementitious components and the fillers and aggregates. Selected properties provided by the manufacturers are listed in Table 4. Some of these, such as the strength, depend on the body coat of the flooring; others depend on the topcoat or sealer, which is variable and not specified. For example, the abrasion resistance would initially depend on the topcoat and later on the body coat. The values listed are apparently for the body coat, but if it is desired to maintain a good topcoat, then the wear resistance of that portion of the floor would be of greater importance. The properties listed show a general increase in strength and toughness for the three Dex-O-Tex products in the order listed. Where possible, corresponding properties for Conductive Selbatuf, as provided by its manufacturer, are also listed.

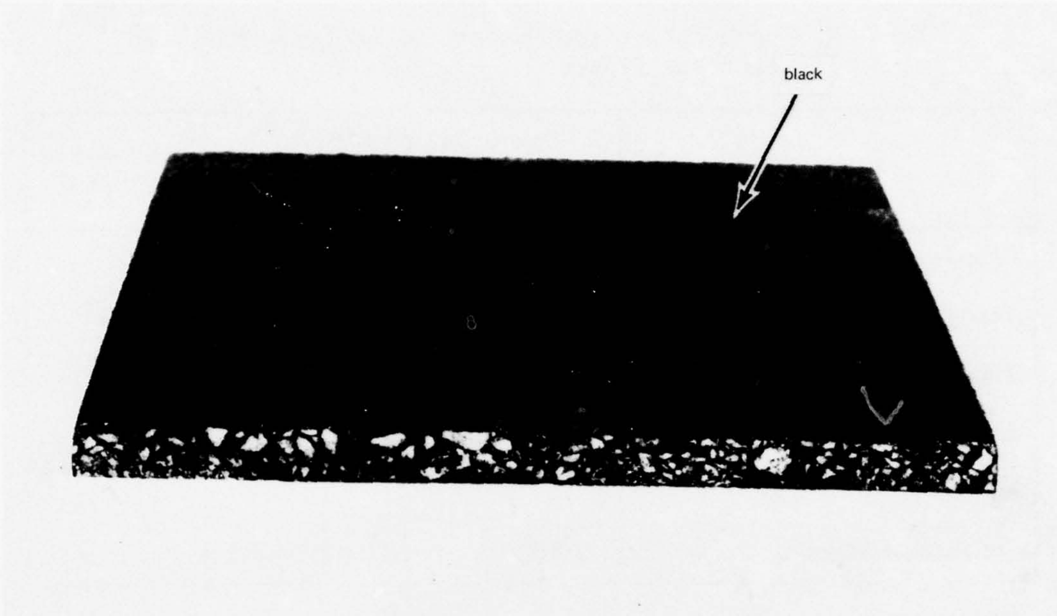

Figure 2. Sample of latex-modified concrete with polyurethane topcoat (Conductive Selbatuf).

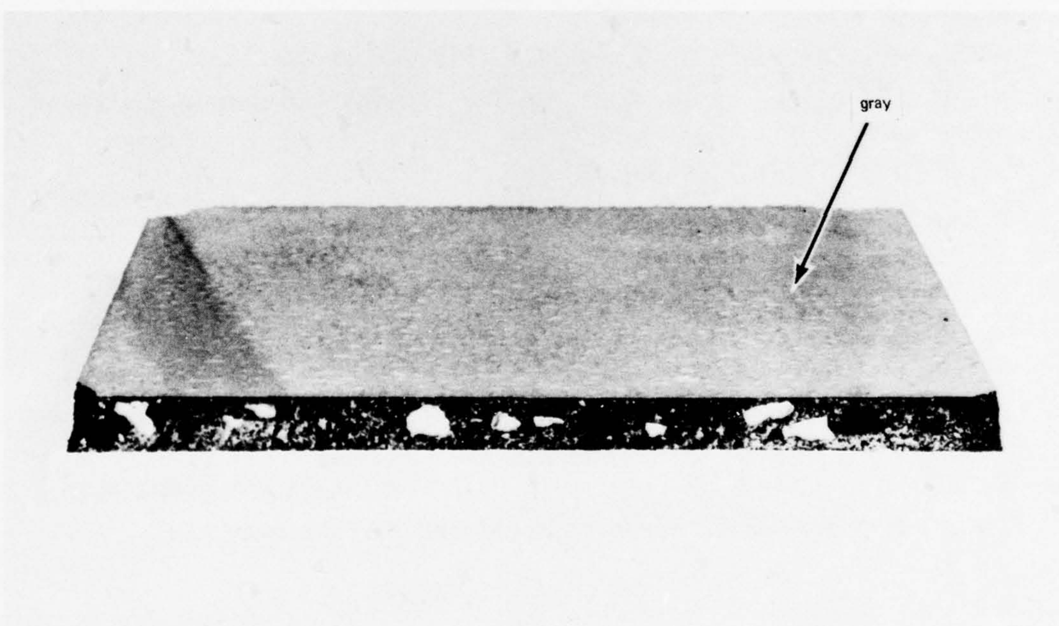

Figure 3. Sample of latex-modified concrete with epoxy topcoat (Industrial-67 Neotex with Cheminert Topcoat).

Table 4. Some Advertised Properties of Latex-Modified Concrete Floors

Property	Dex-O-Tex Floorings[a]			Conductive Selbatuf
	Ind.-38	Ind.-67	HR-321	
Compressive Strength (psi)	1837[b]	3575[b]	6250[b]	5500[c]
Tensile Strength (psi)	470[d]	640[d]	925[d]	925[e]
Indentation	5.4%[f]	1.8%[f]	1.08%[f]	0.8%[g]
Impact Resistance (in.)	0.038[h]	0.021[i]	0.014[h]	0.025[i]
Abrasion Resistance (gm)	0.15[j,k]	0.0965[j,k]	ℓ	0.083[j]
Surface Hardness	D-65[m]	D-73[m]	D-80[m]	

[a]See text for complete designation of the three Dex-O-Tex floorings.

[b]ASTM C-109 (2-in. cubes).

[c]ASTM C-579 (1-in. cylinder, 1 in. high).

[d]ASTM C-190 quoted (but probably should have been the related ASTM C-307).

[e]ASTM C-307 (briquets with min. 1 x 1-in. cross section).

[f]MIL-D-3134 (2,000 lb on 1-in. ram for 30 min), no sample thickness specified.

[g]MIL-D-3134, 1/2-in. thickness.

[h]MIL-D-3134 (indentation after 2-lb steel ball is dropped twice from 8 ft).

[i]Same after ball is dropped once.

[j]Taber Abraser weight loss after 1,000 cycles with CS-17 wheels loaded to 1,000 gm.

[k]Reported as wear index with no load specified, but presumably meant to be weight loss with 1,000-gm loading.

[ℓ]Results given for ASTM C-501 with H-22 wheels are not comparable.

[m]ASTM D-2240 Durometer hardness, reported for the body coat.

The chemical and solvent resistances of the latex-modified concretes depend primarily on the topcoats, provided the topcoats are in good condition and more resistant to attack than the basecoats. Solvent resistances are likely to be less than those of the metallic finish concretes. According to the manufacturer's chemical resistance table, Conductive Selbatuf is not resistant to prolonged exposure to ketones or to chlorinated solvents. Crossfield Products advertises the availability of chemical resistance tables, but did not supply such tables for their LMC floorings. For all the LMCs, exposure to solvents may affect their physical properties, and the areas of greatest wear observed at the facilities visited were at locations where solvents were used.

Conductive Selbatuf was used on various floors at one activity for 7 years (Ref 23). The flooring looked like new in some areas. In an area where solvents and steam were used, the flooring had worn down into the grit coat, presumably because of softening or loss of binder. This damage probably could have been reduced by replacing the worn topcoat, and the damaged area probably could have been repaired by applying grout coats and topcoats. Conductive Selbatuf had been performing well at one other facility contacted (Ref 43), but it was put into layaway status after less than 2 years.* An extensive installation of Conductive Novatraz was the only significant example of conductive terrazzo flooring at the munitions facilities contacted; it performed well under moderate loading, and was reported to provide better slip resistance than metallic finish concrete when wet (Ref 44).

About ten munitions facilities contacted had experiences with Dex-O-Tex LMC flooring. Most of these floorings were the Industrial-67 Neotex, but in some cases, there were uncertainties whether the Industrial-67 or the Industrial-38 formulations were installed. Apparently, none of these facilities had the Neotex-367 flooring, and although one facility had some of the conductive HR-321 flooring, no performance information was available. The Neotex floors were coated with the Cheminert epoxy topcoat at two of the facilities, and with black finishes in all other cases; these were probably the polyurethane D-C Dressing, but the type of topcoat was generally not known.

The Neotex flooring gave good performance in a majority of the cases, but there were also a variety of problems. At one facility, 2-to-4-year-old Neotex floorings of uncertain formulation subjected to light use were in excellent condition (Ref 45). At another facility, a 4-year-old Industrial-67 floor had crescent-shaped depressions from dropped shells and small gouges made by forklifts. However, it was otherwise in good condition, even though steam was used for cleaning and cutting oil was sometimes spilled on the floor (Ref 46). A more recently installed Industrial-67 floor had developed extensive cracks after several months; apparently it was placed over a thick underlayment of Conductive HR-321 flooring that had cracked.

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*According to the manufacturer, this flooring has been used more extensively for floorings and cove bases at hospitals and for flooring aboard ships.

An Industrial-67 flooring that had performed well, except for forklift gouges, was repaired satisfactorily with an epoxy patching compound recommended by the flooring manufacturer (Ref 32). A 10-year-old Neotex flooring (probably Industrial-38) performed well at a detonator loading operation where there was moderate foot traffic. It apparently was resistant to oil, but was badly worn by the legs of a stool that was constantly used. At this location it was patched with an unknown patching compound (Ref 18).

At one activity, local personnel initially had some problems in installing good Industrial-67 flooring (Ref 16). The condition of the floors varied greatly. Many were in good condition, but some had cracks that could have been due to cracks in the underlying floors, and some had ruts from moving buggies. In a solvent recovery room, where the loading was only about 260 lb/in. of width on 12-inch hard rubber tires, the aggregate in the body coat was visible in the ruts. Many of the flooring installations were replacements of deteriorated floors, and often deteriorated floors were repaired by the addition of grout coats or topcoats.

One activity that used the Industrial-67 flooring for 6 years, apparently without topcoat, reported some tackiness produced by oil and damage produced by some solvents, including butyl acetate and ethyl lactate (Ref 47). Another activity had Neotex floors of unknown composition in primer mix houses that were in reasonably good condition; however, a 1-year-old floor had some cracks, and a 5-year-old floor had turned a grayish color which was attributed to the use of hypochlorite solutions (Ref 19). At another location, a new Industrial-67 floor, which was partially replaced by the contractor because of lack of adhesion, had hollow spots and an electrical resistance (measured with dry solid electrodes) of up to 1 megohm (Ref 40).

One of the activities that uses a Cheminert topcoat on Industrial-67 Neotex reports good results and good solvent resistance (Ref 31). Personnel at the activity initially had problems installing this flooring. Floorings had to be replaced that were made with components more than 3 months old, and high resistance readings were obtained when the flooring ingredients were overmixed. Considerable experience was required for proper installation of the Cheminert topcoat. At another location, where a Cheminert topcoat was installed over Industrial-67 Neotex, the flooring developed high resistance after half a year, and the problem was not corrected (Ref 35).

Epoxy Toppings. In these toppings, the epoxy polymer is the binder, and although aggregates and fillers can be used in addition to the conductive ingredients, no cementitious ingredients are expected.

Four conductive epoxy toppings are listed in Table 3. Coroline 510 (Ceilcote Co.) is a system that consists of a thick, troweled-on coating followed by a covering of glass cloth, which is covered by an additional thick coating to produce a 1/8-inch-thick sandwich-type reinforced topping. Dex-O-Tex Cheminert Flooring (Crossfield Products Co.) consists of a thin latex-modified bond coat, a 1/16-inch-to-3/32-inch-thick epoxy base coat with aggregate, and an epoxy topcoat. It differs from all the other toppings in that the conductive ingredient is not carbon black, but aluminum which provides a silvery color. Conductive Sparkproof Industrial BC-5245/46 System (H. B. Fuller Co.) consists of an epoxy mortar about 5/32 inch thick that contains aggregate, an epoxy grout coat about 3/32 inch thick, and an epoxy seal coat about 5 mils thick. The mortar is conductive, but not sparkproof, and the integrity of the grout coat must be maintained to retain the spark resistance. Deco-Rez Conductive Industrial Epoxy Topping No. 115 (General Polymers Corp.) is an epoxy-aggregate mixture that is applied about 1/4 inch thick and is covered with a high solids epoxy coating about 15 mils thick. It is a conductive version of a nonconductive system intended for application over concrete or plywood. A sparkproof version uses a combination of walnut shells and marble fines as the aggregate.

Besides the above floorings, a new glass-fiber-reinforced epoxy conductive flooring is available from Con/Chem, Inc., and Conductive Resolast is available from Duron Maguire Corp. However, no descriptive literature is available for these products. The former has a rough texture apparently caused by fiberglass particles close to the surface, and the latter includes silica sand and apparently is not spark resistant. Both H. B. Fuller and General Polymers, as well as Duron Maguire and others, supply conductive epoxy terrazzo floorings.

Selected physical properties and chemical resistance information for the epoxy floorings are available from the manufacturers, but the methods vary and may not be adequately defined. Sometimes it is not clear whether the information refers to the completed flooring system or to the binders. In general, the epoxy floorings have greater compressive and tensile strengths and are somewhat harder than the latex-modified concretes. The epoxy floorings also have better chemical resistance and abrasion resistance, and this difference may be even more pronounced when the systems are compared with worn-down topcoats.

Among the facilities contacted, there has been extensive experience with only one of the epoxy toppings, Coroline 510. It was installed by local personnel at one plant (Ref 35), even though it is generally applied by authorized contractors. If the flooring is damaged by heavy impact, which may cause spalling of the top layer from the fiberglass, it can be patched easily. The flooring is being used with good results in curing ovens at slightly elevated temperatures, provided the temperatures are not changed too rapidly. At this activity, it has been used in some instances to replace lead flooring, even where nitroglycerine is handled. However, lead flooring is still being used in critical areas. Coroline 510 has been used in areas of moderately heavy loading, but metallic finish concrete is preferred for areas of heavy loading. It has been used also on tabletops. Surface preparation is important, and occasionally buckling or large blister formations have occurred, probably because of moisture migration. Coroline 510 flooring recently has been installed at other facilities (Ref 48-50), but little performance information is available.

The Dex-O-Tex Cheminert flooring system, rather than the Cheminert topcoat on LMC floors, has been used at only one facility that was contacted (Ref 51). The first installation produced a poor flooring that was not resistant to acetone, but a later installation provided a satisfactory flooring.

The Deco-Rez Industrial epoxy flooring was recently installed at one of the activities contacted, but no performance information was available (Ref 20).

There have been some claims that conductive epoxy floorings tend to lose conductivity on aging, but this does not appear to be true for all formulations. However, one of the suppliers reported test formulations that lost conductivity after 1 year, and some nonconductive commercial epoxy floorings reformulated to meet the requirements of the Army guide specifications for conductive flooring (Ref 3) could possibly lose their conductivity on aging.

Polyester Toppings. In these toppings the polyester is the binder. Two polyester floorings are listed in Table 3. The Conductive Ceilcretes 2500 B and 6400 B (Ceilcote Company) have embedded glass cloth like the Coroline 510 epoxy counterpart. These Ceilcretes differ from each other in that the 2500 B is more resistant to alkali and the 6400 B more to acid. Deco-Rez Conductive Ceram No. 150 (General Polymers) appears to be the polyester counterpart to the No. 115 epoxy flooring. It is available in Type I (Conductive) or Type II (Conductive and Nonsparking); the latter formulation uses walnut shells as the aggregate. The Ceram No. 150 meets military specification MIL-F-52505 for a conductive polyester flooring (Ref 4).

The manufacturers' reported physical properties do not show great differences between the polyester floorings and the epoxy floorings. Ceilcote states that their epoxy floorings shrink less and are more flexible than their polyester floorings. General Polymers states that moisture in the concrete subfloor or in the walnut-shell aggregate may prevent proper curing of the polyester, and that the small extra material cost of the epoxy flooring (about $1.20 versus $1.00 per square foot) is well worth expending.

General Polymers also markets a conductive polyester terrazzo, as do other manufacturers.

The Deco-Rez Ceram No. 150 (polyester) has been installed at one of the activities, but no useful performance information is available (Ref 20). The conductive Ceilcrete 6400 B (polyester) has been compared with the Coroline 510 (epoxy) in laboratory experiments in which samples on concrete were subjected to low temperatures. The Coroline withstood the temperature cycling better than the Ceilcrete which lost adhesion (Ref 13).

Coatings

Besides the thicker toppings discussed above, there are also a variety of conductive floor coatings that are applied in thicknesses up to 1/16 inch, but generally much thinner. Such coatings are more often used to convert or revert existing floors to conductive floors than for new construction. Conductive floor coatings, which are listed in Table 5, include ready-mixed coatings (either solvent-based or latices) and two- or three-component solvent-based systems. The coatings may be applied, depending on the type, by brush, roller, spray, or trowel.

The ready-mixed (single-component) coatings require the least application skill, but are likely to be the least durable. Especially for the thinner coatings, the subfloors must be smooth to prevent wear at the raised portions of rough areas. The surface to be coated must be clean to obtain good adhesion. Good surface preparation is especially important for the two-component systems. The phenolic coating and some of the epoxies require primers.

Single-Component Coatings. The most easily applied and most widely used conductive coatings are probably the acrylic latices, which include the Elimstat LX and the Con-Deck Paint. The Elimstat 2200 series are varnishes containing unspecified vehicles that also are readily applied. Conducote is a thick vinyl coating that is applied by trowel. Condutred is a relatively new formulation of a single-component epoxy that replaces a two-component epoxy coating of the same name. Except for the Condutred, the above coatings are all black because of the conductive carbon they contain; the Condutred can be obtained in black or gray.

The Elimstat LX provides a good appearance and good conductivity on smooth concrete floors, but it does not withstand heavy use. At one activity, the Elimstat LX flooring is recoated every 6 months (Ref 23). At another, the coating peeled when it became wet because of poor adhesion (Ref 51). Elimstat LX, which was applied over rough oxychloride concrete flooring, was worn off at high spots on the flooring at another activity (Ref 20). The Con-Deck paint provides a good appearance on oxychloride concrete floors at another activity where it is inspected quarterly and many areas are repainted (Ref 19). Elimstat 2206-8 is used at one activity in an area where there is mostly pedestrian traffic; the coating blisters and loses adhesion when water leaks onto it (Ref 33). Since it does not wear well, it requires frequent recoating with prior stripping to obtain good adhesion.

Conducote, which is a much thicker coating than those discussed above, apparently is suitable for light traffic, but does not wear well in heavy traffic. At one activity, it is recoated in some places at 6-month intervals; nevertheless, it is badly worn in areas of heavy traffic (Ref 21). At another activity, where there is only light traffic, it is recoated every 18 months (Ref 50).

No performance experience is available on the newly formulated Condutred.

Multicomponent Coatings. The multicomponent coatings listed in Table 5 are two-component epoxies and a three-component phenolic. The epoxy coatings do not require separate primers. The phenolic coating requires a Phenoline 305 concrete primer, which is not conductive, and copper tape is used (typically at the edge of the flooring between the primer and the top coat) for electrical grounding.

Table 5. Conductive Floor Coatings

Product	Vehicle	Typical Thickness (mil)	Color	Manufacturer
Single-Component Coatings				
Conducote	vinyl	60	black	Walter G. Legge Co 101 Park Ave New York, NY 10017
Elimstat 2200 Series	varnish of unspecified vehicle	4	black	Walter G. Legge Co
Elimstat LX	acrylic latex	4	black	Walter G. Legge Co
Condutred[a]	epoxy	12	gray or black	Rock-Tred Corp 7440 N St Louis Ave Skogie, IL 60076
Con-Deck Paint W-0731	acrylic latex	4	black	Wescorp Div of Dal Industries, Inc 1601 Sterlin Rd Mountain View, CA 94043
Multicomponent Coatings				
Seal Coat BC-5246[b]	epoxy	5	black	H. B. Fuller Co 315 South Hicks Rd Palatine, IL 60067

continued

Table 5. Continued

Product	Vehicle	Typical Thickness (mil)	Color	Manufacturer
Multicomponent Coatings (continued)				
Epoxy Coating DE3547[b]	epoxy	12	black	General Polymer Corp 3925 Houston Ave Cincinnati, OH 45212
Gilmore & Nolan Groundzol	epoxy	5	gray or black	Standard T. Chemical 10th & Washington St Chicago Heights, IL 60411
Phenoline 304 Conductafloor	phenolic	15	gray	Carboline Co 350 Hanley Industrial Court St. Louis, MO 63144

[a] Formerly a two-component system.

[b] Primarily intended as a topcoat for an epoxy topping.

The Phenoline 304 Conductafloor gave good performance at one activity (Ref 45). However, it lost adhesion at another activity, where poor surface preparation was the suspected cause of failure (Ref 35). Groundzol was extensively used at one activity to restore conductivity to old metallic finish concrete floors (Ref 51). This coating provided good performance, with the only problem being blemishes and bubbling after extensive contact with acetone or steam. Condutred, in the discontinued two-component formulation, was extensively used at another activity directly on concrete and oxychloride concrete (rather than over an LMC flooring produced by the same manufacturer) (Ref 52). It has worn well, and no problems have been encountered. The H B Fuller coating and the General Polymer coating listed in Table 5 are intended primarily as topcoats for the respective epoxy flooring systems discussed earlier. Both manufacturers state that these coatings have been used to restore conductivity to concrete or latex-modified concrete floorings, but no performance information is available.

Coverings

Conductive floor coverings, which are available as tiles or sheeting that are bonded to the floor, are the most resilient of the conductive floorings. The vinyl and rubber tiles listed in Table 6 are available in 1-foot squares. They conform to Federal Specification SS-T-312 (Ref 53), in addition to meeting the conductivity requirements of NFPA 56A (Ref 6). Larger vinyl tiles and vinyl and polyethylene sheeting are available that can be heat-welded after bonding to the subfloors to make seamless floors. In the vinyl and rubber tiles, the conductive carbon is dispersed through the materials as if in threads or blotches to give attractive background colors especially suited for hospital use.

The vinyl or rubber tiles are bonded to the floor with conductive epoxy adhesives. In earlier installations, copper strips were laid below the tiles to help maintain electrical continuity, but this method has been discontinued. The tile manufacturers recommend the concrete subflooring be tested for moisture content before applying the tile.

A conductive linoleum, Congoleum-Nairn Static Conductive Linoleum, was used extensively at one time as an industrial conductive flooring and also in hospitals. It is still in use at some munitions facilities, but is no longer manufactured. Floor coverings that are available are discussed below.

Vinyl Coverings. Two manufacturers currently supply conductive vinyl tile. One of these is the Flexco Division of Textile Rubber Co. (formerly the Robbins Tile Co.), which manufactures FLEXCO Conductive Vinyl Tile. The other is Vinyl Plastics, Inc., which manufactures VPI Conductile. Both companies provide 12-inch tiles, which are laid in the normal manner, and 36-inch tiles, which are intended for heat-welded seamless floors. A sample of a heat-welded vinyl flooring is shown in Figure 4. A vinyl sheeting, Tarkett CONDUCTIFLOR, is manufactured in Sweden and is distributed in the United States. This flooring is 80 mils thick and comes in sheets approximately 6 feet wide by 82 feet

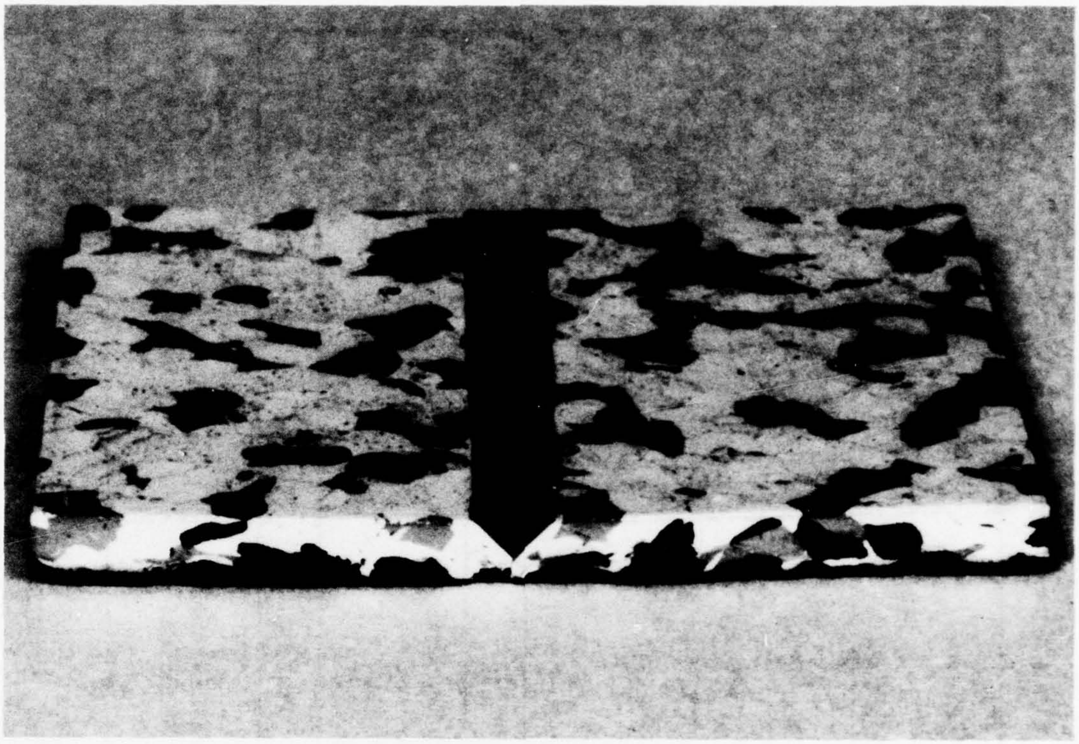

Figure 4. Sample of heat-welded vinyl tile (Flexco).

long. Since the above floorings were all intended primarily for hospitals, the electrical resistance was designed to be less than 1 megohm; therefore, the resistance may often be above the 250,000 ohms allowed by current Army safety regulations.

The vinyl coverings are not intended for heavy industrial use, but where they have been used with generally light to moderate loading, relatively good performance has been obtained. At one activity, large areas of older metallic finish concrete floors were covered by VPI Conductile to provide a floor that would be more dust-free (Ref 36). An older type of tile, 9 inches square by 3/16 inch thick, with a nonconductive epoxy adhesive and copper strips was used. No problems were encountered in most areas, even with occasional forklift traffic that left some rubber deposits on the floor. Oil on the floor presented no problem. However in some areas, the copper strips and adhesive were damaged under heavy loading.

Table 6. Conductive Floor Coverings

Product	Typical Thickness	Manufacturer	Remarks
		Vinyl Coverings	
FLEXCO Conductive Vinyl Tile	1/8 in.	Flexco Div of Textile Rubber Co, Inc P. O. Box 553 Tuscumbia, AL 35674	12 x 12-in. to 36 x 36-in. tiles; can be heat-welded.
VPI Conductile	1/8 in.	Vinyl Plastics, Inc 3123 So 9th St Sheboygan, WI 53081	12 x 12-in. to 36 x 36-in. tiles; can be heat-welded.
Tarkett CONDUCTIFLOR	2 mm (0.079 in.)	Tarkett ab[a] S-370 14 Ronnebyhamn, Sweden	6-ft-wide sheeting; usually heat-welded.
		Rubber Covering	
Burke Condulite	1/8 in.	Burke Flooring Products Burke Industries 2250 So 10th St San Jose, CA 95112	12 x 12-in. tiles.
		Polyethylene Covering	
Velostat (1800 series)	1/8 in.	3M Company Static Control Systems Saint Paul, MN 55101	Polyethylene vinyl acetate sheeting; available in other thicknesses; can be heat-welded.

[a]Represented in the U.S. by Tarco Eastern, Inc, 5030 West Chester Pike, Newton Square, PA 19073; Architectural Floor Products Co, 875 North Lively Blvd, Wood Dale, IL 60191; and Tarco Western, Inc, 342 Harbor Way, South San Francisco, CA 94080.

The newer VPI Conductile (available since 1972), in 36-inch squares, 1/8 inch thick, bonded with conductive epoxy adhesive and heat welded, was installed at another activity. It has given good service for 2 years in an area where trailers weighing up to 6,000 pounds and having pneumatic tires are operated (Ref 54). Cleanup with nonaromatic hydrocarbon solvents produced no problems. At another activity, the VPI Conductile was used for 3 years in a warehouse where it was badly marred by two-wheel skids that left black scoured marks (Ref 19).

The older Robbins vinyl tile, which apparently is similar to the FLEXCO product now available, has been used successfully in an extensive installation at one activity where there is primarily foot traffic (Ref 44).

The Tarkett CONDUCTIFLOR was used at three of the activities. At one activity, it generally adhered well, even with temperatures occasionally reaching below freezing, except for a few areas where there was moisture in the floor (Ref 55). It had good working and wearing properties. At another activity, where it was installed on floors for less than 1 year and also on tabletops, the resistance was about 500,000 ohms (Ref 56). Another activity reported 2 years of use without problems (Ref 57). There was mainly foot traffic, and the flooring apparently had good wear resistance. The use of butyl acetate for cleanup presented no problems.

Rubber Coverings. Burke Condulite is available in 12-inch rubber tiles. It is bonded to the floor with conductive epoxy adhesive. It cannot be heat-welded, but the manufacturer claims that the rubber tends to spread out and seal the seams.

A 1-year-old Burke Condulite floor at one activity appeared in good condition (Ref 36). Gouged-out tiles had been replaced, but a single movement of a 5,000-pound load on vinyl treads presented no problem.

Polyethylene Coverings. A variety of conductive polyethylene materials, such as containers, liners, tools, and aprons, is available for industrial operations where static electricity is a potential hazard. Velostat is the tradename for various conductive plastic materials manufactured by the 3M Company (formerly by the Customs Materials Co.). Velostat Series 1800 are conductive sheets of polyethylene vinyl acetate that are intended as floor runners, floor mats, or tabletops. This material can be heat-welded. A number of munitions activities have installed seamless flooring with Velostat sheeting that was cemented to the floor and subsequently heat-welded.

For most of the conductive flooring materials, variable performances have been reported. However, for Velostat installed as a seamless flooring, poor performances have been reported in almost every case (Ref 16-19, 58).* The chief defects of Velostat used as a seamless flooring are the high coefficient of expansion of the material, the difficulty in obtaining good adhesive bonding (typical of polyethylenes), and the very great swelling caused by contact with hydrocarbon

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*Velostat used for its intended purpose, as floor mats, has performed well at various activities.

solvents or oils. The high coefficient of expansion, as compared to that of the subfloor, may produce buckling at high temperatures or sufficient contraction to rupture the welds at low temperatures.

When an air conditioning system became defective at one activity and live steam entered the room, the Velostat flooring buckled and parted at the welds (Ref 17). At the same activity, oil dripping from machinery caused the Velostat to buckle, lose adhesion, and part at the welds. The only seamless Velostat flooring currently in use that appears in reasonably good condition is also at this activity; the only defects are occasional blistered or raised areas. At one activity, floor mats installed with an adhesive had adhered well to the floor (Ref 50); poor adhesion was reported at another activity (Ref 45).

In laboratory experiments with small samples of Velostat flooring, there were no adhesion problems (Ref 9). In unreported experiments at the same laboratory, adhesion of the Velostat was improved by prior flame treatment of the under surface before using a neoprene contact cement. A Velostat flooring was recently installed with flame-treatment before the application of the adhesive, and the 4 x 8-foot sheets were subsequently heat-welded (Ref 17). Reports indicate that the flooring cracked not only at the seams, but also in the middle of the sheets. It is possible that stresses were induced in the Velostat sheeting during the flame-treatment process, and that the strained areas subsequently crazed, perhaps aided by the solvents in the adhesive.

Other Materials

Besides the flooring materials discussed in the previous sections, there are two other general types of conductive flooring. One is metal sheeting, which is used primarily at munitions facilities. Lead is the metal sheeting most often used, but aluminum has been used occasionally. The other is ceramic tile, laid in a conductive mortar, which is used primarily at hospitals. The ceramic tiles are about 1 inch square and are available in various shades of brown, because iron oxides are used to provide the conductivity.

Lead Sheeting. Lead flooring is extensively used at munitions activities. It has the advantage of being very impervious and being softer than concrete. Lead is also very resistant to acids and to most chemicals and solvents that may be used. Lead has a disadvantage in that it may deform permanently under moderate loads if the wheels are too firm, and especially if the wheels repeatedly travel over the same track. Lead is expensive and requires high skills for installation, especially in the wiping (or soldering) of the seams.

The thicknesses of the sheeting used at the facilities that were contacted vary from 1/4 inch to 1/16 inch, or from 16-pound lead to 4-pound lead, respectively. (The latter are the weights per square foot of the lead sheeting.) A representative of the Lead Manufacturer's Association suggested 16-pound lead should be used, but a representative of a lead supplier thought 8-pound lead would provide ample thickness.

Both these weights of lead sheeting can be wiped or soldered with lead cut from the same sheeting. Six-pound lead apparently is the limiting weight for wiping by an experienced lead wiper. Another method for sealing the seams is to slightly overlap the lead sheets and peen the seams with a hammer; however, a slightly raised area might remain. This method has not been used at any of the facilities contacted.

Chemical lead is most often used for flooring. This lead contains a small amount of copper (about 0.04 to 0.08%) and is slightly harder and more durable than pure lead (also called corroding lead). Sometimes antimony lead (containing about 4 to 7% antimony) is used because it is still harder and more durable. The Brinell hardness of corroding lead may be about 3 units, chemical lead about 4.5 units, and 6% antimony lead about 7.5 units.*

Because lead is sold by the pound, 8-pound lead is only half as expensive per square foot as 16-pound lead. The installation of 8-pound lead should also be appreciably less expensive because larger sheets can be used that will require somewhat less wiping. The 8-pound lead is available in 8.5 x 25-foot rolls weighing about 1,700 pounds. Antimony lead is slightly more expensive than chemical lead - about 50 cents per pound as compared to about 45 cents per pound.

An 8-pound lead flooring laid over 1/8-inch asbestos matting has been used with good results at one activity (Ref 35). An exception occurred where heavy carts (2,000 pounds on pneumatic tires) eventually left noticeable depressions. (Generally, lead is placed directly on concrete.) Because of the health hazard, asbestos matting is no longer considered a good construction material. Four-pound lead flooring has been used with good results at another facility (Ref 58). At this facility, the flooring was bonded to the concrete with a contact adhesive and was not wiped; it was laid like tile, and the seams reportedly are quite well sealed because of the ductility of the lead. At another facility (Ref 18), both 12-pound lead and 16-pound lead have been used; the latter thickness is preferred because it is believed to last longer.

Both 8-pound and 16-pound lead have been used at another facility (Ref 17); the former apparently bulges more readily with thermal expansion and contraction, and some cracks have been experienced that have been sealed by wiping. An 8-pound lead, placed directly on concrete, has been used with good success at another facility (Ref 59), where 550-pound barrels are let down vertically onto the floor. A 12-pound flooring of 6% antimony lead, on 1/16-inch to 1/8-inch asbestos paper, has provided good service with rolling traffic at another facility, where 10-pound lead also has been used over smooth subfloors and for light traffic (Ref 16).

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*What hardness was envisaged when "a soft material like lead" was specified for initiating explosives in AMCR 385-100 is not known, nor is it known whether the hardness of the flooring in this general range is really a critical factor.

Thus it appears that 8-pound, or 1/8-inch, lead can be used where there is only foot and light-wheeled traffic on soft treads, provided the subflooring is very smooth and the wheel traffic does not continually follow the same track. Any roughness in the subfloor would be transmitted through thin lead flooring, and the effect of wheeled traffic following the same track would be greatly intensified. Where heavier usage is encountered, 12-pound or 16-pound lead might be more appropriate. No information appears to be available as to how much more tolerant antimony lead is to wear and whether 8-pound antimony lead could be equivalent to 12-pound or 16-pound lead in wear or load resistance.

Aluminum Sheeting. Aluminum sheeting, especially aluminum tread plate, is much more resistant to wear than lead sheeting. But it is not as inert as lead, nor as soft or ductile, and its coefficient of expansion differs greatly from that of the typical subflooring.

Aluminum tread plate has been used satisfactorily at one activity where the plates are loosely held to the floor; however, the floor is difficult to clean (Ref 19). At two other activities, where the aluminum sheeting covered the whole floor and was welded into place, buckling occurred because of the difference in thermal expansion of the aluminum and the concrete subfloor; and the floors had to be removed.

SELECTION OF CONDUCTIVE FLOORING

The first step in the selection of conductive flooring is to determine the operational requirements and compare these with the characteristics of prospective floorings. The second step is to determine the compatibility of prospective floorings with the explosives that will be handled. The third step is to consider the installation problems and costs associated with prospective floorings.

Performance Characteristics of Flooring Materials

No single conductive flooring material is available that will meet the requirements for all types of uses because these requirements vary greatly. Very tough floors are needed where forklift trucks operate or where dollies with hard wheels and heavy loading are used. Resilient floors are desired in areas where primary explosives are handled; also, resilient floors are desired for the comfort of personnel, where possible. Impervious floors are required where explosive powders or liquids are handled. Floors resistant to solvents and chemicals are required where appreciable amounts of these contact the floors.

The general performance characteristics of the various types of conductive floorings that were discussed earlier have been compiled in Table 7. The information listed is, of necessity, qualitative.

General Uses of Flooring Materials

At the risk of greatly oversimplifying, and assuming proper installation, appropriate uses for the different categories of conductive floorings are listed below.

Metallic Finish Concrete - These are the hardest and toughest of the conductive floorings and are intended for wheeled traffic and heavy industrial use. They may be more difficult to repair or replace than some of the other floorings.

Oxychloride Concrete - This flooring is for comparatively light use and where there is no continuous flooding with water.

Latex-Modified Concrete - This flooring is for general use where traffic is not as heavy as that tolerated by the metallic finish concrete. Compared with metallic finish concrete, it is more resilient and easier to repair or to replace. Depending on the topcoat, it may have more limited solvent resistance.

Epoxy Toppings - This flooring is for general use. It has better resistance to most chemicals than the floorings discussed above. However, all epoxy floorings do not necessarily give the same performance, even if they are installed in accordance with the same general specifications.

Polyester Toppings - These may be less expensive than the epoxy toppings, but they may have less advantageous physical and chemical properties.

Organic Coatings - These vary from two-component coatings having good chemical resistance to single-component coatings that may provide temporary rejuvenation of a no-longer-conductive floor.

Vinyl Coverings - These may be good for light general use where a lighter-colored, easily cleanable, resilient floor is desired. However, the solvent resistance may be low.

Polyethylene Coverings - These are useful only as runners or for matting.

Lead Sheeting - This is for locations where a very impervious and chemically resistant floor is required, and where loading is not too heavy.

Compatibility

The compatibility of a prospective flooring with the explosives that will be handled usually must be determined by the prospective user. Many munitions activities have determined compatibilities by the vacuum stability test or by thermal analysis, for the specific floorings and the explosives of interest. But there is no collection of this information, which would be voluminous if the test results included all conductive floorings in combination with all explosives or explosives

Table 7. Performance Characteristics of Conductive Flooring

Property	Performance Characteristics of the Following Flooring Types[a,b]									
	Concretes		Organic Composition Toppings			Coatings		Coverings		Metal
	Metallic Finish	Oxychloride	Latex-Modified Concrete	Epoxy	Polyester	Single-Component	Multi-Component	Vinyl	Polyolefin	Lead
Electrical resistance[c]	low	S[d]	S	S[e]	S	S	S	S[f]	S	low
Spark resistance	S[g,h]	S	S[h,i]	S[h,i]	S[i]	S	S	S	S	S
Compatibility with explosives[j]	I	I	I	I	I	I	I	I	I	S
Imperviousness[k]	S	I	S	S	I	I	S	S	S	high
Resilience[l]	low	low	low[m]	low	I	low	low	moderate	moderate	moderate
Slip resistance[n]	S	S	S	S[o]	S	I	I	S	low	S
Indentation resistance	high	S	S	S	S	S	S	moderate	S	moderate
Impact resistance	high	I	S	S	S	I	I	S	S	low
Abrasion resistance	high	low	S[p]	S	I	low	S	low	I	low
Adhesion to subfloor[q]	S	S	S	S[q]	S[q]	S[q]	S[q]	S	low	I
Resistance to temperature changes	S	I	S	I	I	I	I	S	low[r]	S
Resistance to water	S[s]	moderate	S	S	S	S[t]	S	S	S	S
Resistance to solvents[u]	S[v]	I	moderate[w,x]	S	moderate[y]	low	S	moderate[y]	low[z]	S
Resistance to chemicals[aa]	S[bb]	moderate[cc]	S	S	S	I	S	S	S	S

[a] General properties are given for the various commercially available conductive floorings within each type listed.
S = generally satisfactory performance with respect to this property. I = insufficient information to categorize.

[b] Commercially available floorings within the types shown are listed in Tables 2, 3, 5, and 6.

[c] Floorings shown as having low electrical resistance will not meet Navy minimum resistance requirements, but effectively remove static electricity.

[d] Electrical resistance is high if the flooring becomes dry.

[e] Electrical resistance is low for Coroline 510.

[f] Electrical resistance may be slightly above the 250,000-ohm Army maximum resistance limit, but below the 1 megohm Navy maximum resistance limit.

continued

Table 7. Continued

[g] May spark if improperly installed.

[h] May spark if surface is worn off.

[i] May spark if sand or silica fillers are used. Some of the floorings are formulated without sand or silica to make them spark-resistant. Other floorings are covered with a topcoat without aggregate that will prevent sparking as long as its integrity is maintained.

[j] Any potential effect of the flooring on the stability of explosives handled will vary for different explosives and must be individually determined.

[k] High resistance to absorption of explosives and lack of retention of explosives in surface imperfections or cracks are important for the cleanability of flooring. The imperviousness may be considerably reduced if the flooring surface becomes worn.

[l] Low resilience indicates a harder floor.

[m] Low to moderate resilience, depending on the latex used.

[n] Low slip resistance indicates a floor that is slippery, especially when wet.

[o] Slip resistance may be low if the finish is smooth or worn smooth.

[p] Abrasion resistance is reduced if the topcoat is worn off.

[q] Adhesion may be greatly reduced if the surface preparation is inadequate or if the subfloor becomes moist (especially for some of the floorings indicated).

[r] May lose adhesion, buckle, or crack at seams with small changes in temperature.

[s] May become rusty on prolonged exposure to hot water.

[t] Some coatings are not resistant to prolonged wetting and lose adhesion.

[u] The resistance to solvents may vary considerably with the solvents used and the time of exposure. The resistance of a specific flooring to a specific solvent may be obtainable from the manufacturer. Properties given are based on the general composition of the flooring and assume short contact times associated with spillages.

[v] Organic curing agent remaining on the flooring may have low solvent resistance, but the curing agent is not required for the integrity of the flooring.

[w] The solvent resistance may be reduced if the topcoat is worn off.

[x] May be affected by ketones, aromatic solvents, and chlorinated solvents.

[y] Vinyls are likely to be affected by ketones, aromatic solvents, and chlorinated solvents; some polyesters may also be affected.

[z] Strongly affected by oils and petroleum solvents.

[aa] The resistance to aqueous chemical solutions does not include possible effects of strong acids or alkali. The resistance to specific chemicals may be obtainable from the manufacturer. Prolonged contact time for kill solutions is assumed.

[bb] Not resistant to acids and salts; may be damaged by strong oxidants.

[cc] May be damaged by dilute acids.

mixtures that might come into contact with the floorings. Information on the compatibility of various types of plastics with various explosives has been collected by Picatinny Arsenal (Ref 60) and by PLASTEC (Ref 61-63). However, this information generally is not directly applicable to any specific conductive flooring, which may be a modification of some plastic listed or may contain different plastics in the successive layers of the flooring.

For TNT, the compatibility is generally related to the basicity of the flooring, because TNT is less stable under alkaline conditions. Although some epoxies are compatible with TNT, epoxies are generally incompatible with TNT; polyurethanes are generally compatible (Ref 23); and polyesters provide still less compatibility problems (Ref 51).

Installation

The availability of highly qualified commercial applicators (with very specialized experience) or of local capabilities is an important factor in the choice of conductive flooring. A majority of the problems with conductive floorings are related to improper application. If flooring is to be renewed or replaced, an important consideration is the amount of surface preparation needed for various new floorings, including removal of existing flooring. The cost of installation also is an important factor.

Costs

Typical costs of materials for conductive floorings, as provided by the manufacturers, are listed in Table 8. These costs, which are for the materials that would be placed on a concrete subfloor that is in good condition, vary considerably even within the types listed. For the metallic finish concrete, the costs of materials include only the conductive hardener and the conductive curing compound, not the grounding system that would be installed in the flooring. The cost of the installed floors are also listed in Table 8, but these values are very rough estimates. Many manufacturers are not willing to quote even approximate figures because the contractor's cost can vary so widely, depending on plant location, manpower availability, and other factors.

SPECIAL PROBLEMS RELATED TO CONDUCTIVE FLOORING

Maximum and Minimum Resistance Requirements

The Army's AMCR 385-100 requires a maximum resistance of 250,000 ohms from the conductive flooring to ground; it requires no minimum resistance. NFPA 56A requires a maximum resistance of 1,000,000 ohms between any two points three feet apart on the floor; it requires a minimum resistance of 25,000 ohms between two such points or between any point and ground. A few years ago, the Navy had the same electrical

Table 8. Costs of Conductive Flooring

Conductive Flooring	Approximate Cost ($/sq ft)	
	Materials	Installed Floor[a]
Metallic Finish Concrete	0.60[b]	3.00[c]
Metallic Aggregate Concrete	10.00	-
Latex-Modified Concrete	0.75	4.50
Epoxy Topping	2.00	5.00
Epoxy Coating	0.30	-
Vinyl Tile	2.00	4.00
Lead (16-lb)	8.00	15.00
Lead (8-lb)	4.00	-

[a]Installation by contractor over existing subflooring; these values may vary widely.

[b]Conductive hardener and curing compound only; does not include ground rods, etc.

[c]Rough estimate of cost beyond that of ordinary reinforced concrete flooring.

resistance requirements as the Army, but NAVSEA OP 5 now has the same 1,000,000-ohm maximum resistance limit as NFPA 56A, and it has a minimum resistance that depends on the electrical power that is supplied.

The Navy minimum resistance requirements for conductive flooring are "5,000 ohms in an area with 110-volt service and 10,000 ohms in areas with 220-volt service." Although no minimum resistance is cited for areas without electrical service, some readers have the impression that a minimum resistance of 5,000 ohms is still required. The Navy type specification for metallic finish concrete provides a space for insertion of a minimum resistance of 5,000 ohms or 10,000 ohms, without indicating that perhaps neither figure need be specified (Ref 7). Left open is the question of any minimum resistance requirement if all electrical service is in conduits and there is no danger of contact of personnel with electrical power. However, since significant potential and current flow have been detected on hooks of overhead cranes, some persons believe that power supplied in conduits also provides a significant hazard.

The minimum resistance is specified as a protection of personnel against shock from electrical power sources. Some protection against electric shock is already provided by the conductive shoes that are required to be worn on the conductive flooring. In the Navy regulations, such shoes are required to have a minimum resistance of 25,000 ohms. (However, this minimum resistance is for both shoes in series with the body of the wearer; therefore, one shoe could have a very low resistance. If the two shoes have the same resistances, the minimum resistance in parallel would be about 6,000 ohms.) Whether the additional minimum resistance requirement for the floor is really warranted has been questioned, especially in view of the fact that all metal equipment and containers are grounded and provide a direct short to ground.

Many individuals contacted, and especially those concerned with plant operations, believe strongly that the lower the resistance, the better. They believe that protection against shock from electrical power need not be provided by the flooring because other safeguards are taken. For example, electricians working on live circuits are required to wear nonconductive shoes or use rubber mats. Furthermore, where electronic tests are made on ordnance, insulating mats are used.

Where minimum resistances are required, many types of conductive flooring are ruled out. These include lead floors, most new metallic finish concrete, and Coroline 510. Also ruled out would be open grid mezzanines and other metal floorings.

The electrical problems of low resistance floors or metal floors are a general industrial problem that is not limited to ordnance facilities. Perhaps this problem should be dealt with in electrical codes or regulations and should not be solved by a requirement placed on conductive floors.

Electrical Resistance Measurement

Electrical resistance measurements of conductive flooring were discussed in detail in a prior CEL report (Ref 9). Partly as a result of the recommendations made, NAVSEA OP 5 now specifies the same method of measurement and the same upper resistance limit that are specified by NFPA 56A for conductive flooring in hospitals.

Electrodes and Contact Surfaces. Electrical resistance measurements as specified by NFPA 56A and NAVSEA OP 5 are made with two resilient electrodes placed three feet apart or with one such electrode and a connection to ground. The 5-pound electrode has a contact area of 5 sq in., which is covered by rubber and by aluminum foil. The dry electrodes are used on dry flooring surfaces.

The corresponding Army regulations in AMCR 385-100 specify the use of one solid metal electrode and a ground connection. This metal block also weighs 5 pounds and has a 5-sq-in. contact area. If the flooring is uneven, making it difficult to obtain 5 sq in. of contact, a thin coating of "electrode jelly (brushless shaving soaps)" may be applied to the underside of the block.

Most of the Army activities visited used shaving cream in their electrical resistance measurements, and the resistances without shaving cream were not known. One Navy activity (Ref 44) used shaving cream to obtain good contact and another (Ref 40) used saline solution. Both had floors that gave acceptable readings with these aids, but gave unacceptably high readings without them.

From a safety standpoint, it would be best if the floors were measured under their worst, but realistic, conditions. The upper resistance limit should be measured under the lowest humidity encountered and before the floors are washed to remove interfering dirt and thereby inadvertently moistened for better conductivity. The conductive shoes worn on conductive floors would make much better contact than metal blocks and a resilient electrode would give more realistic resistance readings. However, the floor would not normally be covered by shaving cream or saline solution, and the use of these aids to give acceptable resistance readings might lead to a false sense of security.

Electrical Resistance of Wetted Concrete Floors. To determine the effect of wetting on electrical resistance measurements, electrical measurements were made on two conductive floors having high resistances (both directly and through conductive shoes) and on two dry concrete slabs. Each floor was tested dry and again when wetted. Resilient electrodes, as specified in NFPA 56A (Ref 6) and in NAVSEA OP 5 (Ref 2), were used rather than the solid metal electrodes specified in AMCR 385-100 (Ref 1). The results are shown in Table 9. All of the dry floors had very high electrical resistances. The effect of water or brushless shaving cream was generally the same; in most cases, it provided much lower resistance readings. Even one of the nonconductive concrete slabs became very conductive when wetted with water or shaving cream. With solid metal electrodes, the differences between dry and wet floors would probably be much greater. These results further indicate that the use of resilient electrodes and the elimination of brushless shaving creams as a contact agent appear desirable.

Ohmmeters and Test Voltages. AMCR 385-100 suggests a test voltage of 90 to 500 volts applied to the instrument, which presumably is the open circuit potential. No further requirements are placed on the meter. (For testing conductive shoes on a wearer, a maximum current of 2.0 mA is specified, which would be the short circuit current.)

The ohmmeter specified by NFPA 56A and by NAVSEA OP 5 has an open-circuit potential of 500 volts DC and a short-circuit current of 5 mA, and, therefore, an effective internal resistance of 100,000 ohms. Such a meter is suitable for measuring the 25,000-ohm minimum resistance of hospitals floors, which would register at 80% of full scale; but it would be less suitable for measuring a 5,000-ohm minimum resistance limit that would register at about 95% of full scale (and, therefore, be barely different from the full scale reading of the short circuited meter).

In actuality, instrument makers do not like to manufacture and do not provide the instrument specified. The meters currently sold and used in hospitals have an effective internal resistance of about 200,000 ohms. Such a meter when measuring a 5,000-ohm resistance will have an output voltage of 12 volts and will register at 97.6% of full scale. Without special calibration at the time of measurement, such meters cannot distinguish a 5,000 ohm reading from one twice that magnitude or from zero.

Table 9. Effect of Wetting of Electrodes in Conductive Flooring Measurements[a]

Flooring	Test Floor No.	Measurement Method[b]	Electrical Resistance (Ω)		
			Dry Floor	Wet Floor	Shaving Cream Contact
Metallic Finish Concrete	1	E-G	5M	125k	-
Metallic Finish Concrete	1	E-E	11M	550k	-
Metallic Finish Concrete	2	E-G	1M	400k	400k
Metallic Finish Concrete Through Conductive Shoe	2	E-G	1.25M	200k	225k
Dry Concrete Slab	3	E-E	1.2M	1.0M	1.0M
Dry Concrete Slab	4	E-E	4.0M	1.6k	3.2k

[a]Measured according to NFPA 56A method.

[b]E-G = one electrode to ground.
E-E = between two electrodes 3 feet apart.

The substantiating calculations for the above discussion are listed below and the output voltages and meter readings for various measured resistances are listed in Table 10.

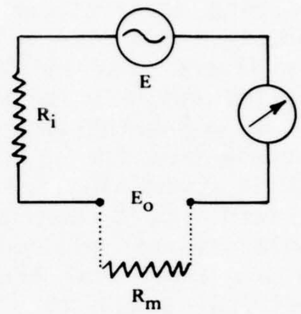
The electrical potential provided by the meter (E) (in this case 500 volts) will be divided between the internal resistance (R_i) of the meter, and the resistance being measured (R_m) according to the ratios of these resistances. There will be an internal drop in voltage (E_i), and the drop across the measured resistance will be the effective output voltage (E_o); thus,

$$E = E_i + E_o \quad \text{and} \quad E_o = E - E_i$$

The current flowing through the measured resistance will be the same as that flowing through the meter and through the whole system, and since $I = E/R$,

$$\frac{E_o}{R_m} = \frac{E}{R_i + R_m} \quad \text{and} \quad E_o = E\frac{R_m}{R_i + R_m}$$

The meter reading is proportional to the current flowing through the meter and, therefore, proportional to the voltage drop across the internal resistance. The portion of the full scale reading is, therefore, E_i divided by E. Since,



$$E_i = E - E_o = E - E\frac{R_m}{R_i + R_m}$$

the portion of the full scale reading is

$$\frac{E_i}{E} = 1 - \frac{R_m}{R_i + R_m}$$

and the percentage is 100 times this amount.

If minimum resistances of 5,000 ohms have to be measured, it would probably be best to use the same electrodes, but replace the meter with an ordinary ohmmeter. The test voltage would then be lower, but the readings would be more meaningful.

Table 10. Characteristics of Ohmmeters

Measured Resistance (Ω)	Internal Resistance 100,000 Ω		Internal Resistance 200,000 Ω	
	Output Voltage[a]	Reading (% of full scale)	Output Voltage[a]	Reading (% of full scale)
0	0	100.0	0	100.0
5,000	24	95.2	12	97.6
10,000	45	90.9	24	95.2
25,000	100	80.0	56	88.9
100,000	250	50.0	167	66.7
250,000	357	28.6	278	44.4
1,000,000	455	9.1	417	16.7
Infinite	500	0.0	500	0.0

[a]With open circuit potential of 500 volts.

Grounding of Conductive Flooring

Both AMCR 385-100 (Ref 1) and NAVSEA OP 5 (Ref 2) specify maximum electrical resistances to ground for conductive floors, but do not state how the floors should be grounded. Both safety manuals mention permitted grounds to which a floor presumably could be connected and also nonpermitted grounds. For metallic finish concrete, very specific grounding instructions are given in the specification (Ref 7), but no grounding instructions are given in other specifications applicable to conductive flooring. NFPA 56A for hospital floors states that conductive floors must be connected to the room ground point, but does not describe how this point should be connected to the conductive floor.

If grounding does present a problem, it is primarily in the method of connecting the conductive flooring to an electrical conductor rather than in connecting the conductor to earth ground. The connection of an electrical conductor to conductive flooring should not be critical and should present no problems if the construction sequence of the flooring and the electrical properties of the materials are kept in mind. The electrical conductor in contact with the flooring should preferably be flexible, like copper gauze or copper ribbon, but rigid plates attached to the subflooring may also be suitable. The conductor should be placed in an area and embedded sufficiently so that it will not be damaged.

It is important that the copper gauze or ribbon be in intimate contact with a conductive layer of the flooring. For example, an organic composition topping (on a properly prepared surface that may already have been covered with an underlayment) may consist of many layers. These may include a nonconductive bond coat to provide adhesion to the concrete subfloor, followed by a nonconductive waterproof membrane to prevent transfer of moisture. This may be followed by the body coat or conductive matrix that is the main portion of the flooring. The body coat may be covered and smoothed with two conductive grout coats, and finally the sanded floor may be covered with two conductive topcoats. The copper gauze or ribbon would be quite useless if it were placed below the nonconductive waterproof membrane. Ideally, it might appear desirable to embed the electrical conductor in the bodycoat matrix, but this matrix might contain aggregate that is too large to allow a layer of bodycoat both below and above the electrical conductor. Placing the electrical conductor above the bodycoat would cover it with only the grout coats and topcoats which would not give sufficient protection. Therefore, in this system, the electrical conductor that is to be connected to earth ground should be placed below the bodycoat. In any other system care must be taken to assure the electrical conductor is not separated from the floor surface by any nonconductive layer.

In many cases, the placement of an electrical conductor that is connected to earth ground is not necessary to achieve a reasonably low resistance to ground. For example, in an evaluation of coatings on concrete floors that previously had excessive resistances to ground of about 100 megohms, electrical conductors were embedded below the coatings. For the finished coated floors, no differences were observed in the resistance readings to ground (about 100,000 ohms) when the electrical conductors were attached to a ground point or when they were left unattached (Ref 51).

The above situation is not surprising. If the resistance to ground from a 5-sq-in. electrode is 100 megohms, and if the floor were then covered with a conductive coating or other surfacing that increased the effective contact area between the electrode and the original flooring a thousandfold, the new resistance to ground of the same electrode would be 100,000 ohms.

Some manufacturers suggest that special direct grounding of their floors is not necessary. This is probably true, provided the subfloor is not insulated from ground and no insulating membranes are added or formed in the installation procedure. It can be argued that if the flooring provides the required conductivity to ground, the actual path of the current flow is not important. However, it can also be argued that direct grounding would provide an added margin of safety.

The grounding of conductive floors at Naval hospitals and ordnance activities is discussed in a recent CEL publication (Ref 64).

Reconditioning of Conductive Flooring

Sometimes floors are in fairly good structural condition, but have lost their conductivity. This situation often occurs with older concrete or oxychloride floors. Some activities have achieved good results by using coatings to restore the conductivity of their floors.

At one activity, the metallic finish concrete floors were wet-ground with an electric terrazzo grinder to bring the resistance down to acceptable values (Ref 23). These floors reportedly had metal filings sprinkled through the top 1-inch layer. Because the metal filings and the carbon are usually in the top 1/8 inch of the floor, extensive grinding would normally remove the conductive layer. Also, the removal of the metallic finish may eliminate the spark resistance by exposing sand particles in the concrete. Two other activities used terrazzo polishing equipment, but were unable to restore the conductivity of their floors (Ref 31, 48). (Floors containing toppings of portland cement with carbon throughout the mix might benefit from terrazzo grinding. Such floors are not spark resistant.)

Some conductive floors are maintained with conductive waxes. When these become dirty, or when nonconductive waxes are unintentionally used, the floors may lose conductivity. Removal of such wax and, if appropriate, re-waxing with a conductive wax may restore the conductivity. Master Builders offers a conductive wax for Masterplate floors. A military specification for conductive wax has recently been cancelled.

Many conductive floors have conductive sealers specified by the flooring manufacturers to protect the surface, to seal small pores, or to help maintain humidity in oxychloride or portland cement concretes. Sealers are more permanent than waxes, but they may wear away or become embedded with dirt. Some are intended to be stripped and replaced periodically.

Latex-modified concrete floorings usually have topcoats that are more permanent than sealers. As explained earlier in the discussion of these floorings, if the topcoat wears off, it should be replaced to protect the base coat and to cover any aggregate that is not spark resistant.

CONCLUSIONS

1. The performance characteristics of conductive flooring and the performance experiences that are presented can be used as guidelines in the selection of conductive flooring.

2. Conductive flooring should be chosen with the end-use in mind. For example, metallic finish concrete has good wear and solvent resistances, but poor acid or salt resistances. Latex-modified concrete is good for general light industrial use, but may have inadequate solvent resistance. Lead is impervious, but is expensive and may not resist heavy loading.

3. Problems with conductive flooring are often caused by improper methods of application. Proper installation may often be more important than the choice of flooring.

4. Problems with conductive flooring are sometimes caused by lack of resistance to chemicals or solvents used in the munitions operations or by excessive mechanical stresses on the flooring.

5. Very low resistance values, which are not indicative of the safety provided by the flooring, may be obtained by the use of contact agents with solid metal electrodes in the measurement of the electrical resistance, as specified in AMCR 385-100. The use of resilient electrodes as specified by NFPA 56A, without contact agents, should give more meaningful values.

6. The maximum resistance limit of one megohm, specified by NFPA 56A and NAVSEA OP 5 for conductive flooring, provides adequate protection against static electricity. An increase of the 250,000-ohm limit in AMCR 385-100 to the above value (as measured without contact agents) would be desirable.

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Appendix A

REQUIREMENTS FOR CONDUCTIVE MUNITIONS FLOORING

Properties of conductive flooring are discussed, and related test methods are given. For some of the properties, there are accepted test methods, many of which are American Society for Testing and Materials (ASTM) methods or are methods of Federal Test Method Standards (FTMS) or of military specifications. For some of the other properties, there are no good accepted test methods, but there are related tests that have been used.

CONDUCTIVITY

Conductivity requirements and methods of movement have been discussed in detail in the main text under the heading of "Special Problems Related to Conductive Flooring."

Conductivity measurements of all conductive flooring at munitions facilities are required initially and semiannually thereafter.

SPARK RESISTANCE

Conductive flooring must not spark when struck with hardened steel tools. Although most tools used in ordnance operations are sparkproof, many hardened tools are still in use. Ordinary concrete floors and floors with silica inclusions would not be sparkproof. The proper application of a metallic finish hardener will render concrete floors sparkproof, and floors with silica inclusions may be made sparkproof by the application of suitable topcoats. If such a topping or topcoat is worn off as the flooring is used, it will no longer be sparkproof.

The Army and the Navy safety regulations require that no sparks be produced when the floor is stroked vigorously with a hardened steel file. An Army guide specification for industrial resinous flooring (Ref 3) and a Navy type specification for metallic finish concrete (Ref 7) require that the floor be tested for spark resistance by stroking it vigorously with a 12-inch hardened steel file in a 3-foot arc. Generally, the file is held at arm's length and a 3-foot arc is scribed on the floor with the tip of the file. This test is conducted in subdued light.

For determining the spark resistance of a moderately conductive decking, a military specification (Ref 65) uses a rotating stiff wire wheel on an electric drill as well as glancing blows from a steel hammer.

Where specified, tests for spark resistance are made on new flooring, but no subsequent testing is required.

COMPATIBILITY

Although not mentioned in the Army or Navy safety regulations, it is important that the flooring be compatible with the explosives that are processed, so that explosives spilled on a floor will not, by virtue of their contact with the floor, become more sensitive or dangerous to handle. The flooring should also be unaffected by the explosives. If the flooring consists of layers and the upper layer or topcoat is likely to be worn off during use, then any exposed layers must be compatible with the materials handled.

It is difficult to determine the effect of the flooring on explosives that remain in contact with it over a prolonged period of time at room temperature, for example, in cracks or inaccessible areas. To simulate this, any reaction is accelerated in the vacuum stability test that is performed at 100C for 40 hours (FTMS 406, Method 7081) (Ref 66). In this test, differences in gas evolution between the explosives and the flooring heated separately, and the explosives and flooring heated together in an intimate mixture, are determined. Considerably increased gas production in the mixture at this elevated temperature is taken as an indication of incompatibility at ambient temperature. Compatibility can also be determined by differential thermal analysis that will detect reaction or gas evolution in a mixture of an explosive and a flooring sample as it is slowly brought to an elevated temperature.

IMPERVIOUSNESS

Conductive flooring must be free of cracks or open seams to prevent any buildup of spilled explosives. The floor must also not absorb any component of the explosive, such as nitroglycerin or plasticizers. Although "imperviousness" is not a commonly used word, it connotes a floor that is continuous and impenetrable, and one that can be cleaned easily. This property has also been called cleanability.

Some aspects of imperviousness can be visually noted; for instance, the ease by which a wetted and wiped area dries may be an indication. The absorption of nitroglycerin, plasticers, or solvents can sometimes be detected by a reduction of the hardness after exposure to these materials (for example, in a small dammed-up area covered by a watch-glass). Test methods for resistance to solvents and chemicals (discussed below) also are related to imperviousness.

RESILIENCE

The Army safety regulations require floors of lead or other soft flooring material where initiating explosives are handled. At several Army ammunition plants, this requirement has been interpreted to mean a resilient floor. At several Navy ordnance facilities, concern has been expressed that available conductive floorings are not sufficiently resilient. Resilience of the floor reduces the shock of impact to material that is dropped onto the floor. This implies that substantial energy of the impact is absorbed by the floor; but the floor surface must not be deformed permanently or it will not repeatedly serve the same function.

The term "resilient" as applied to flooring, readily produces a feeling for what is meant, but there appears to be no good definition of this quality. Webster's definition – "returning freely to a previous position, shape, or condition" – could apply equally well to a soft rubbery surface or to a hard steel plate.

Resilience has been described as the ability of a floor to absorb the impact associated with walking, thus providing underfoot comfort; and qualitative comfort ratings have been given, which range from excellent for carpeting and very good for cork, to very poor for concrete (Ref 67). The initial indentation under load (with subsequent recovery) has been referred to as the "comfort value" (Ref 39).

Resilience is also described in technical terms as the amount of energy stored in a material, or more specifically the strain energy per unit volume (Ref 68). This reduces to:

$$\text{Resilience} = \frac{f^2}{2\,E}$$

where f is the applied force, and E is the modulus of elasticity.

There appear to be no available methods for measuring the resilience of flooring. Federal Test Method Standard No. 501a on the sampling and testing of resilient floor coverings (Ref 69) does not include a test for resilience. (It does list a number of rheological tests that are related to this elusive quality.) ASTM D 1054 for Impact Resilience and Penetration of Rubber by the Rebound Pendulum measures the percentage of rebound (which is dependent on the energy absorbed) and also the penetration into the sample (Ref 24). ASTM D 2632 for Impact Resilience of Rubber by Vertical Rebound measures the percent of rebound of a special 28-gm plunger that is dropped 40 cm (Ref 24). There are a variety of indentation tests that are indirectly related to resilience.

SLIP RESISTANCE

For personnel safety, munitions flooring should not be slippery. Skid resistance and non-slip property are other terms used for this property.

Several slip meters for measuring the coefficient of friction are commercially available. Such a slip meter is used in a test method of MIL-D-21631 (Ref 65). In a test method of MIL-D-3134 (Ref 5) the friction factors for a 2 x 4-inch flooring specimen are measured under 33 pounds of load, on rubber and leather surfaces, each dry, wetted with salt water, and wetted with oil.

LOAD RESISTANCE

Different types of resistance to loading depend on the type or manner of application of the load. Resistance to static loading can be expressed as indentation resistance, which measures the effect of heavy loads on about a square inch of surface, or as hardness, which is the resistance to indentation by a small conical indenter with relatively light loads. (Hardness has been related to resilience as discussed above.) Related to dynamic loading are impact resistance, to a steel ball, shock resistance, to high impact loading, resistance to rolling load, which may include a shearing action, and abrasion resistance, which is resistance to abrasive shear, generally associated with foot traffic. A hard floor has a high indentation resistance; a brittle floor has a low impact resistance.

For measuring indentation, the method of MIL-D-3134 (Ref 5) applies a force of 2,000 pounds to a flat, circular square inch of surface for 30 minutes and allows a 1 to 7% indentation. FTMS 501a for resilient floor coverings (Ref 69) lists both a flat foot and a spherical foot indenter. The latter is similar to ASTM F 142, Indentation of Resilient Floor Coverings (McBurney Test) (Ref 70), which places a 30-pound load on a 1/4-inch spherical foot.

Hardness is usually measured by the indentation obtained with conical indenters. Several methods are available, depending on the hardness of the material. For softer materials, the Shore or Durometer hardness is measured in accordance with ASTM D 2240, Indentation Hardness of Rubber and Plastics by Means of a Durometer (Ref 70). Shore A hardness for softer materials and Shore D hardness for harder materials are obtained by using different conical indentors having flattened or slightly rounded tips, respectively. For materials generally in the Shore D hardness range, ASTM D 2583, Indentation Hardness of Plastics by Means of Barcol Impressor (Ref 71), may be used to obtain a Barcol number. This instrument is portable and has a spring-loaded indentor. For still harder materials, ASTM D 785, Rockwell Hardness of Plastics and Electrical Insulating Materials (Ref 71), is used. Unfortunately, there is no direct relationship between the scales of these various methods.

For impact resistance, the method of MIL-D-3134 uses a 2-pound steel ball dropped 8 feet and expects no visible sign of chipping, cracking, or detachment from a steel plate, and less than 1/16 inch of permanent deformation.

For resistance to rolling loads, MIL-D-21631, a specification for latex concrete deck coverings for ammunition spaces (Ref 65), includes a test for live load resistance. A flooring sample is reciprocated in 5-inch strokes under a 4-inch brass roller, 3-1/8 inches wide, loaded from 1,000 to 3,000 pounds. The change in sample thickness is determined by initial and final measurements at a roller pressure of 400 pounds. Conductive flooring for munitions operations normally would be subjected to smaller loadings than those used in the above test. No corresponding tests are required, and such information is not generally available for these floorings. One manufacturer does report some indentations produced by smaller loads on smaller casters of different compositions, which are intended to simulate the loads of hospital operating tables.

ABRASION RESISTANCE

Abrasion resistance, or wear resistance, is one measure of the durability of a floor. Abrasion resistance generally refers to resistance to foot traffic as opposed to the effects of rolling equipment, which generally are related to load resistance.

Taber Abrasers are most often used to determine the wear properties of plastics (FTMS 406, Method 1091, Abrasion Wear; Ref 65) or of coatings (FTMS 141a, Method 6192, Abrasion Resistance; Ref 72). In these test methods, abrasive wheels roll on a rotating flat specimen, and the weight loss of the specimen or the depth of wear is determined. Several different abrasive wheels, or "calibrase wheels," are available, and various loads can be placed on these wheels. For floor coatings, a typical calibrase wheel is No. CS-17, which may be used with a 1,000-gram load. The results are sometimes recorded as the wear index, which is the loss in weight in miligrams per 1,000 cycles of abrasion. For a flooring system consisting of more than one layer, the abrasion resistance measured is that of the top layer, unless the wear extends beyond that layer. The abrasion resistance of the flooring may change substantially after the upper layer is worn off.

A complicated wear test machine, which simulates the effects of walking, is used to measure resistance to wear in a test method of MIL-D-3134 and of MIL-D-21631 (Ref 5 and 65). In this test, 2 x 4-inch specimens are alternately lifted and dropped under a 10-pound load onto a large rotating disc containing aluminum oxide grit. The wear must be less than 0.15 inch after 1,500 revolutions, which is deeper than most topcoats that might be used.

ADHESION TO SUBFLOOR

Most conductive flooring is laid, cast, or coated onto concrete or other subfloorings and is held in place by an adhesive bond. Failure of this bond can produce lifting or buckling, or a breaking off or spalling of brittle flooring. Adhesion can be affected by temperature changes, especially when the conductive flooring has a different coefficient of expansion from that of the subfloor and when large temperature changes are involved.

There are no generally accepted test methods for the adhesion of conductive flooring. A shear test for adhesive strength of toppings is given in MIL-D-3134 and in MIL-D-21631 (Ref 5 and 65), but this test is for toppings applied to steel surfaces.

RESISTANCE TO TEMPERATURE AND HUMIDITY CHANGES

Conductive flooring should be resistant to changes in temperature and humidity. As mentioned above, wide temperature changes can cause loss of adhesion when coefficients of expansion of the flooring and the subfloor vary greatly. At elevated temperatures (for example, in drying rooms), there also could be problems in softening or in accelerated deterioration. High humidity could also cause deterioration, but the major problem is that the conductivity of some floorings is changed by humidity. High humidity generally produces higher conductivity or lower electrical resistance, and a low humidity produces higher resistance. Resistances should be within specifications under all humidities that will be encountered.

There are a variety of temperature and humidity exposure test methods. There is no reliable method for determining whether adhesion will be lost because of temperature changes. Good performance of a small test specimen does not necessarily indicate the performance of larger installations where larger strains will be produced. The coefficient of expansion can be determined by ASTM D 696, Coefficient of Linear Thermal Expansion of Plastics (Ref 71). A comparison with the coefficient of expansion of concrete would give the strain that is produced, but not the stresses that can be endured without loss of adhesion or without cracking.

RESISTANCE TO WATER AND CLEANING AGENTS

Conductive flooring should be resistant to water spills and to any cleaning agents that may be used, including steam. This requirement, which has also been called cleanability, is similar to the chemical resistance requirements discussed below.

RESISTANCE TO SOLVENTS AND CHEMICALS

Conductive flooring must not be damaged by solvents spilled accidentally or used intentionally in cleanup operations or by oil dropped from machinery. The flooring must also withstand kill solutions that are used to deactivate spilled explosives.

Resistance of plastics to solvents and to chemicals is usually determined by immersing a test specimen in a liquid medium and determining changes in weight and dimensions over a period of time (for example, 7 days in ASTM D 543, Test for Resistance of Plastics to Chemical Reagents; Ref 71). But immersion tests are applicable only to uninstalled floor coverings and to unsupported topping samples. For other flooring systems, the backs and sides of typical samples would be different from the wearing surface. For testing such systems, the solvent or chemical must be applied to the flooring surface where it may produce observable visual changes. The solvent or chemical can also be placed in a dammed-up area covered by a watchglass, and in addition to visual changes, tackiness or softening may be determined.

OTHER PROPERTIES

Besides the above properties, there are other general properties of importance that include the ease of installation of the flooring, the ease of repair of damaged flooring, and in some cases, the ability to bridge minor cracks in the subfloor. Also, fire resistance can be very important.

Information supplied by manufacturers of conductive flooring often includes compressive, tensile, and flexural strength, which are all related to load resistance. The flexural strength of the conductive flooring is particularly important for supported flooring, as opposed to flooring on grade, since any bending of the subfloor must be accommodated.

Appendix B

INSTALLATION OF METALLIC FINISH CONCRETE

The applicable specification for metallic finish concrete is a Navy type specification, TS-09701, Metallic-Type Conductive and Spark-Resistant Concrete Floor Finish (Ref 7). Because the conductive portion of the finished flooring is near the surface, ground rods or studs, each with an attached disc of copper mesh reaching within about 3/8 inch of the finished surface, are embedded in the slab at 20-foot intervals. The hardener or dusted-on metallic surfacing material is applied immediately to the freshly poured and floated floor twice at 0.9 lb/sq ft; each application is followed by mechanical floating. A conductive curing agent is applied to the finished floor, and the floor is protected against damage or excessive evaporation for 30 days.

The above specification calls for the application of the dusted-on finish to a 1-inch topping on a base slab. The manufacturers or providers of the metallic hardener generally prefer the application of this material to a monolithic slab, or alternatively to a topping more than 1 inch thick. Some of the reasons given include (1) the 1-inch toppings sometimes lose their bond because of poor surface preparation of the base slab or (2) improper use of a bonding agent. Although the application of the surface hardener should not materially affect this adhesion, such loss of adhesion may be blamed on the supplier of the hardener. In very warm areas, if the topping is applied without a retarder, the open time that is allowed for the dusting on of the finish and mechanical floating is too short with a 1-inch topping. It would be greater with a thicker topping or a monolithic floor that could provide more water to wet the hardener. Where a topping is installed, a 100% solids epoxy bonding agent is generally considered preferable to the cement grout slush bond coat or the slush bond coat with metallic aggregate that are suggested in the type specification, partly because of the better adhesion provided, and partly because of the greater open time allowed for the pouring of the topping. However, a large number of epoxy bonding agents are available, and some reportedly perform considerably better than others.

The flooring must be well protected during the 30-day curing period to prevent loss of moisture. For indoor construction, the application of the conductive curing compound will provide this protection. However, for outdoor construction in a warm or dry climate, the flooring should be completely covered during the initial moist curing period, without any portion of it being exposed to the atmosphere.

The type specification calls for the removal of the conductive curing compound before acceptance tests are made, even though in general industrial practice, such curing compounds are allowed to remain on the floor. The specification lists two acceptance tests: one for electrical conductivity and one for spark resistance. The passing of these tests does not necessarily establish good workmanship. For example, if such a floor were split in half by a large crack, electrical continuity between these halves would still be maintained since both halves would be tied to ground. The specification also states that the manufacturer of the dusted-on metallic surfacing materials shall supervise all phases of the work, whereas, in practice, the suppliers of the conductive hardeners provide technical assistance but not supervisory control.

Appendix C

DESCRIPTION OF LATEX-MODIFIED CONCRETES

Conductive Selbatuf, manufactured by Selby, Battersby Co., is an industrial flooring system that uses an acrylic latex as part of the binder in the LMC. It consists of a prime coat that is applied to the concrete subfloor, a grit coat that forms the main body of the system, a grout coat that is primarily for filling voids, a polyurethane topcoat, and a sealer. Copper screening can be placed under the conductive prime coat for grounding the floor. The conductive grit coat comprises most of the 1/8-to-1/4-inch thickness of the flooring. The grit coat, after drying overnight, is sanded before applying one or two grout coats, which are of the same composition as the prime coat. The topcoat is a conductive, two-component polyurethane formulation that is applied in three or more coats (minimum drying time of 2 to 3 hours between coats) to give a minimum dry-film thickness of 6 mils. It has a higher wear resistance and chemical resistance than the acrylic-latex-modified concrete that forms the bulk of the flooring. In areas of high abrasion, additional coats of the topcoat are recommended. Two coats of a sealer should be applied to protect the flooring while it cures. Light traffic can commence after 1 day, but heavy traffic or chemical exposure should be avoided for 7 days. The flooring is not resistant to prolonged exposure to ketones or chlorinated solvents.

The Selby, Battersby Co. supplies an acrylic-latex-modified cementitious terrazzo floor, Conductive Novalite, that has marble chips in the same matrix as the above grit coat. However, after grouting and polishing, it does not receive a topcoat, but only clear seal coats. The same manufacturer previously supplied poly(vinyl chloride)-modified industrial and terrazzo floorings, called Conductive Selbatex and Conductive Novatraz, respectively. It has also announced a new Conductive Selbalon, similar to the Selbatuf, but with a more wear-resistant Hypalon topcoat.

The largest supplier of conductive latex-modified concrete flooring is Crossfield Products Corporation, which provides its products under the trade name "Dex-O-Tex." It also uses the trade name "Neotex" for many of its latex-modified concretes. Thus, conductive Dex-O-Tex floors are not necessarily LMCs; for example, Dex-O-Tex Cheminert flooring is essentially an epoxy flooring.

Crossfield Products provides four conductive industrial LMC floorings. These are each described by the manufacturer as trowel-applied composition floors, the essential components of which are a water-phase elastomer or resin and a factory-blended powder containing dehydrating components, undisclosed chemicals, and graded aggregates. The names of the four floorings and their chief differences are given below.

Dex-O-Tex No. 303 Conductive Neotex Industrial-38: This flooring is intended for areas of light to medium traffic and rolling loads and where some structural flexing of the subfloors can be expected, as on wooden subfloors or on balconies. The substrate may be concrete, metal, or wood, but wood may require special surface preparation. The liquid component of this system is a neoprene latex containing conductive acetylene carbon black. Mixed with a powder, this liquid component is used to prepare a surface-wetting mix or bond coat that also is used later as a grout coat. When mixed with a factory-blended powder containing aggregates, it is used to prepare the 1/4-inch-thick body or wear coat. The latter is sanded, grouted, and covered with a sealer or topcoat.

Dex-O-Tex Conductive Neotex Industrial-67: This flooring is also called Dex-O-Tex P-67 Conductive Industrial Neotex. It is intended for areas of medium to heavy foot traffic and rolling loads. The intended substrate is concrete, but the flooring may be applied on properly prepared metal surfaces. The liquid component of the 1/4-inch synthetic mastic wear coat is a copolymer latex of undisclosed composition, and the conductive carbon is contained in the powder component that also contains the cementitious material and the aggregate. The liquid component of the bond coat generally is a neoprene latex, and the same material can be used for the grout coat.

Dex-O-Tex Conductive Neotex-367: This flooring is very similar to the Dex-O-Tex P-67, except that the conductive carbon is the liquid component of the 1/4-inch body coat. Because of the greater stability of the components and greater ease of application, the manufacturer prefers this newer formulation.

Dex-O-Tex Conductive HR-321: This flooring is designed for areas subject to heavy industrial type traffic or where additional thickness is required to smooth slightly irregular concrete or to create slope for drainage. This flooring can be applied over properly prepared metal, but not wood. The liquid component of the 3/8-to-1/2-inch body coat is an acrylic copolymer latex containing the conductive carbon.

The four Dex-O-Tex flooring systems can be covered by one of the following three conductive sealers or top coats: (1) AJ-53C Dressing - An emulsion resin sealer applied in two coats, requiring 2 hours drying time between coats. (2) Conductive Dee Cee Dressing, or D-C Conductive Colorseal - A two-component polyurethane applied in two coats, requiring 12 hours drying time between coats, to obtain a 6-mil dry film thickness. This dressing is intended for areas of medium to heavy traffic subjected to occasional chemical spillage. (3) Conductive Cheminert Topcoat - A two-component epoxy system with aluminum pigmentation applied in two coats, requiring 12 hours drying time between coats to obtain a 6-mil dry film thickness. This topcoat is intended for areas subject to spillage of chemicals and solvents. (It is the same as that used on the Dex-O-Tex Conductive Cheminert Flooring.)

The Dex-O-Tex flooring materials normally are applied only by approved contractors. However, two DOD munitions facilities that had employees trained by Crossfield Products do install their own Dex-O-Tex floorings. There are sometimes minor variations in procedures and nomenclature between the flooring systems prepared by the Western and Eastern branches of Crossfield Products and between the procedures at the two munitions facilities. These differences are primarily in the compositions of the primer or bond coats and of the grout coats and in the compositions of the aggregates used.

Crossfield Products also supplies a noeprene-latex-modified cementitious terrazzo flooring called Dex-O-Tex 303 Conductive Terrazzo, and also a terrazzo flooring made with a latex of undisclosed composition called Dex-O-Tex P-610 Conductive Terrazzo. The former is more flexible than the latter; the latter sets up faster than the former.

A coating of nonconductive Magnabond often is used as a primer over the cleaned concrete subfloor, especially under the Neotex-367 or the HR-321. Sometimes nonconductive waterproofing membranes, consisting of reinforcing fabric embedded in a neoprene latex composition, are used. Any copper screening used for grounding the flooring system is placed above any nonconductive layer.

Appendix D

EXCERPTS FROM ARMY'S

SAFETY MANUAL

AMC Regulation 385-100*

Chapter 7 - STATIC ELECTRICITY

7-5. CONDUCTIVE FLOORS

a. Conductive floors and conductive shoes shall be used for grounding personnel at operations where explosives such as primer, initiator, detonator, igniter, tracer, and incendiary mixtures are exposed. Some material sensitive to static sparks (easily ignited or detonated) are lead styphnate, lead azide, mercury fulminate, tetrazene, diazodinitrophenol, potassium chlorate-lead styphnate mixtures, igniter composition, grade B magnesium powder, and black powder dust when exposed in layers. Dust of solid propellants can also be ignited from the spark energy that can be accumulated on a person and conductive floors and shoes must be employed when the dust is present. In addition, dust-air mixtures of ammonium pictate, tetryl, tetrytol, and dust of solid propellants are sensitive to static electricity discharge. Many flammable liquids and air mixtures tested (ethyl ether, ethyl alcohol, ethyl acetate, acetone, and gasoline) can be ignited by static discharge from a person. When personnel come into the proximity of (possible contact with) explosives or mixtures enumerated above, conductive floors shall be installed except where the hazards of dust-air or flammable vapor-air mixtures are eliminated by adequate housekeeping, dust collection, ventilation, or solvent recovery methods.

b. Conductive floors also are required where operations are performed involving:

(1) Loose unpacked ammunition with electric primers.

(2) Exposed electro-explosive devices; e.g., squibs, detonators, etc.

(3) Electrically initiated items with exposed electric circuitry; e.g., rockets.

*Reference 1 of this report.

(4) Hazardous materials that could be ignited by a static discharge from the human body.

c. Conductive floors and footwear are not required throughout an entire building or room if the hazard remains localized. In such cases, conductive mats or runners may be used where required.

d. Personnel, except electricians, in locations where conductive floors are required and installed shall wear conductive footwear (see paragraphs 10-11 and 16-18g). Nonconductive gloves shall not be worn in such locations. Electricians are not to work in a building or room containing exposed explosives. They must wear nonconductive shoes for electrical work. In addition, when observing explosives operations to check on performance of equipment, they shall be provided with conductive booties or other grounding devices.

7-6. CONDUCTIVE FLOOR SPECIFICATIONS

Conductive floors must be of nonsparking material such as lead, conductive rubber or conductive flooring composition and shall meet the following requirements in addition to those given in paragraph 5-3.

a. The flooring and its grounding system must provide for electrical resistance measured between ground and a 5-pound electrode in direct contact with five square inches of floor area not to exceed 250,000 ohms.

b. The surface of the installed floor must be free from cracks and reasonably smooth, and the material must not slough off, wrinkle or buckle under operating conditions.

c. Where conductive floors and shoes are required, the resistance between the ground and the wearer shall not exceed 1,000,000 ohms; i.e., total resistance of conductive shoes on a person, plus the resistance of floor to ground. Where conductive floors and shoes are required, table tops upon which exposed explosives or dusts are encountered should be covered with a properly grounded conductive material meeting the same requirements as those for flooring. See Figures 7-1 and 7-2.*

7-7. CONDUCTIVE FLOOR TESTS

a. Initial tests shall be made of all conductive floors and subsequent tests shall be made at least semiannually. The test results shall be permanently recorded with a copy filed in the Safety Office. Instruments used in making tests shall be used only when the room is free from exposed explosives. The instrument used should be portable, self-powered, enclosed unit and should consist of two dry electrodes. One

*Not included.

electrode shall consist of a special metal block (five pounds in weight), which makes contact with five square inches of floor area. The block should be equipped with a nonmetallic strap to enable pulling it along the surface of the floor under test. If the flooring is uneven, making it difficult to obtain five square inches of contact, a thin coating of "electrode jelly" (brushless shaving soaps) may be applied to the underside of the block. The other electrode should consist of a suitable spring test clip for attachment to a permanent ground. The electrodes shall be insulated from each other and should be connected with instruments by test leads of such length that all parts of the floor can be reached, and connected in such a manner that the resistance between electrodes may be measured as shown on Figure 7-3.* The operation and maintenance of test instruments shall be entrusted to competent personnel.

b. The voltage applied to the instrument should be between 90 and 500 volts. Low voltage instruments may be used, but if the floor shows more than the maximum permitted resistance with instruments of less than 500 volts, a test with a 500-volt instrument should be made before any action is taken to gain greater conductance. If the resistance is then greater than 250,000 ohms, and the floor and electrodes are free from insulating materials, the effectiveness of the floor grounds shall be tested.

Note 1: Paragraph 5-3, FLOORS AND WORK SURFACES, which is referred to above, is as follows:

Floors and work surfaces in explosives facilities shall be constructed to facilitate cleaning and to preclude insofar as possible cracks or crevices in which explosives may lodge. Sub-floors, finished flooring, and work surfaces must not wrinkle or buckle under operating conditions. In chemical munitions facilities, surfaces must be sealed by a coating or treated to prevent agent adsorption during spills so that complete decontamination can be obtained. No porous material should be used for flooring where there is danger of agent contamination. Coating or sealing materials must not react with agent. Where washing is required, surfaces must be capable of withstanding repeated applications of hot water. In explosives facilities and locations where the atmosphere may contain combustible dusts, or flammable vapors or gases, ferrous metal surfaces shall not be coated with aluminum paint due to the potential sparking hazard. Nonsparking floors and work surfaces are required in all locations where exposed explosives are present. Nonsparking floors and work surfaces must not spark when stroked vigorously with a hardened steel file. Locations requiring conductive flooring are specified in paragraph 7-5. When grounding is necessary, the provisions of paragraph 7-2 apply to work surfaces. Cove bases at the junction of walls and floors are recommended. Exposed nails, screws or bolts in work surfaces must be avoided.

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*Not included.

Note 2: Paragraph 14-2, PROPERTIES OF INITIATING EXPLOSIVES, contains the following sentences:

Rooms in which initiating explosives are handled shall have floors of lead or other soft flooring material complying with the requirements of paragraph 5-3. Unless the static electricity hazard is otherwise eliminated, the flooring also shall be conductive (paragraph 7-6).

Appendix E

EXCERPTS FROM NAVY'S

AMMUNITION AND EXPLOSIVES ASHORE

Safety Regulations for Handling,
Production, Renovation and Shipping

NAVSEA OP 5*

Volume 1, Chapter 4 - ELECTRICAL REQUIREMENTS

4-7.2.4 Conductive Floors

a. Specifications. Conductive floors may be made of lead, conductive rubber or plastic, conductive masonry material, or conductive composition material. Floors must comply with the following requirements:

(1) The surface of the floor must be free from cracks and reasonably smooth. If washing of floors is necessary, the material as installed must be capable of withstanding repeated washing with hot water. If conductive floors are to be waxed, a conductive wax that provides the same conductive characteristics shall be used.

(2) The material must not produce sparks when stroked briskly and firmly with a hardened steel file.

(3) The material must not slough off, wrinkle, or buckle under normal conditions of use.

(4) The average resistance of the conductive floor shall be 1,000,000 ohms or less as measured between two electrodes placed three feet apart. The average resistance of the conductive floor to building ground shall also be 1,000,000 ohms, or less. The average resistance shall be determined as described in paragraph 4-8.2.2b.

(5) The resistance of the floor shall be more than 5,000 ohms in areas with 110-volt service and 10,000 ohms in areas with 220-volt service, as measured between a permanent ground

*Reference 2 of this report.

connection and an electrode placed at any point on the floor, and also as measured between two electrodes placed three feet apart at any points on the floor. This minimum is specified as an additional protection against electrical shock.

(6) Where conductive floors and conductive shoes are required, table tops on which exposed explosives or electro-explosive devices are handled or where explosive dust is encountered shall be covered with properly grounded, conductive, sparkproof material.

b. Use of Conductive Floors. Conductive floors are mandatory in areas where personnel work with or are exposed to contact with the materials listed in paragraphs 4-6.4.1 through 4-6.4.3 or other materials known to be static sensitive. Conductive shoes or other devices providing similar protection shall be worn in areas where conductive floors are mandatory. Sparkproof shoes should be worn in conjunction with steel reinforced concrete floors. Where the need for conductive floors is localized, they need not be installed throughout the building.

4-8.2.2 Conductive Floor Testing

a. General Requirements. Conductive floors shall be tested at the time of installation and at least semiannually thereafter. In areas exposed to large variations in relative humidity, additional measurements should be made during times of lowest relative humidity and highest relative humidity to ensure adequate floor conductivity. The tests shall determine if the floors meet the requirements of paragraph 4-7.2.4a. The results of these tests shall be posted in a log and maintained on file.

b. Method of Test.

(1) The floor shall be clean and dry and the room shall be free of flammable gas mixtures or explosive dusts.

(2) Each electrode shall weigh five pounds and shall have a dry, flat circular contact area 2-1/2 inches in diameter, which shall comprise a surface of aluminum or tin foil 0.0005 to 0.001 inch thick, backed by a layer of rubber 1/4 inch thick and measuring between 40 and 60 durometer hardness as determined with a Shore Type A durometer (ASTM D-2240--68).

(3) Resistance shall be measured with a suitably calibrated ohmmeter, which shall operate on a nominal open-circuit output voltage of 500 volts DC and a short-circuit current of 5 milliamperes with an effective internal resistance of 100,000 ohms ±10%.

(4) For both electrode-to-electrode and electrode-to-ground, measurements shall be made at five or more locations in each room and the results averaged. For compliance with paragraph

4-7.2.4a(4), the average shall be below the limits specified and no value shall be greater than five megohms. For compliance with paragraph 4-7.2.4a(5), no location shall have a resistance less than that specified. Where resistance to ground is measured, two measurements shall be made at each location, with the test leads interchanged at the instrument between measurements; the average of the two measurements is to be taken as the resistance to ground at that location. All readings may be taken with the electrode or electrodes more than three feet from any ground connection or grounded object resting on the floor. If the resistance changes appreciably with time during a measurement, the value observed after the voltage has been applied for about five seconds shall be considered to be the measured value.

c. Use of Test Instruments. Instruments for testing the conductivity of floors shall be used inside the room only if the room is free of explosives and no exposed electro-explosive devices are present; otherwise, the test instrument shall be placed outside the room. In any case, the floor in the immediate area of the electrode contact shall be thoroughly cleaned of all explosive material and the air purged of explosive dust or vapors.

DEPARTMENT OF THE NAVY

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