TECHNICAL REPORT
68-20-CM

DIRECT MOLDED SOLE BOOTS

by
Alice F. Park and Douglas S. Swain

September 1967

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

Clothing and Organic Materials Laboratory
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FOREWORD

The development of Direct Molded Sole (DMS) construction for the U.S. Army's tropical and all-leather combat boots represents a major breakthrough in military footwear. The predominant area of failure in welt construction Army footwear in the past has been the boot bottom -- broken or rotted welt and outsole stitching, loose or missing nails and heels, and burned midsoles. In the DMS process, the sole and heel are molded directly to the boot upper on high-pressure vulcanizing machines, eliminating the stitching and nail failures which made welt footwear so unsatisfactory.

The new DMS boots were developed under the Army's post-Korean War research and development program to improve combat footwear. After unsuccessful attempts to significantly improve welt footwear, the Army investigated the new DMS process being used commercially for street shoes. U. S. Army Natick Laboratories (NLABS) technologists adapted the DMS process and developed the special footwear materials and designs necessary to obtain vulcanized boots which would meet military requirements.

This report reviews the postwar need for better tropical and leather combat footwear, NLABS development of the DMS process and boot materials to meet that need, and current DMS research.

Grateful acknowledgment is made to Mr. Clyde Vanatta, plant manager of Safety First Shoe Company, Huntsville, Alabama, for his many contributions to the design, development and fabrication of the Army's DMS tropical combat boot.

S. J. KENNEDY
Director
Clothing & Organic Materials Laboratory

APPROVED:

DALE H. SIELING, Ph.D.
Scientific Director

W. M. MANTZ
Brigadier General, U.S.A.
Commanding

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ABSTRACT

The U.S. Army Natick Laboratories have modified a method of footwear construction known as Direct Molded Sole (DMS) for the Army's tropical and all-leather combat boots. NLABS developed the special component materials, boot designs and fabrication techniques required to produce military footwear by the DMS process. The sole and heel of the new DMS boots are molded directly to the boot uppers on high-pressure vulcanizing machines, eliminating the sole stitching and heel nailing which were the major points of failure in welt combat footwear. The DMS boots are significantly more durable and more comfortable than welt construction boots, and will save the military money both in production cost and by reducing boot repair and maintenance problems. The DMS process has enabled NLABS to incorporate special protective features into the tropical combat boot, including a steel innersole to resist penetration of the boot bottom by punji stakes, and a wedge shank to deflect and absorb the impulse of antipersonnel land mines.

DIRECT MOLDED SOLE BOOTS

1. Introduction

A new boot sole construction is revolutionizing U.S. military footwear. For the first time soldiers are wearing boots with bottoms so durable that they outlast the uppers. The new construction, known as Direct Molded Soles (DMS), is a method of vulcanization modified by the U.S. Army first for its tropical combat boot, and now for its all-leather boot (Figure 1).

Since the first DMS tropical boots were produced in the early 1960's, the Army has sent more than 3½ million pairs of the new boots to U.S. soldiers and marines in Southeast Asia. More than 200,000 pairs of an all-leather combat boot also constructed with the vulcanized soles were issued this spring after the first quantity production. Eventually it is hoped to convert all military combat and field footwear to the DMS construction.

Presently, U.S. military footwear and most leather shoes for men are made with a welt construction, in which the sole components are machine-stitched to the shoe upper, and the heel is nailed to the sole in a series of operations. An average of 366 sole stitches is required on a pair of welt shoes(1). In contrast, the entire bottom of the new DMS tropical boot is vulcanized directly to the boot upper in one operation that eliminates all stitching.

To produce a DMS boot, two "biscuits" of uncured rubber, one each for the sole and heel, are placed in a machine mold conforming to the desired bottom size and tread design. A finished boot upper is slipped over a metal last and the last is locked in a standing position over the mold (Figure 2). The vulcanizing machine automatically applies the proper pressure and heat required to "knit" the two biscuits into a one-piece sole and heel, while simultaneously bonding the boot bottom to the upper. After 15 minutes, the machine automatically releases the last from the mold and a new boot is ready for use.

The advantages of the DMS process become apparent when the new DMS tropical boot is compared with the World War II welt boot it replaces. The World War II tropical boot had a stitched, welt sole, a leather lower foot and a canvas upper. The soles and heels tore loose or wore down after 3 or 4 weeks of exposure to the constant wetting and drying action, and the deep mud of the jungle terrain(2). U.S. Army Special Forces troops are wearing the new DMS tropical boots under the same conditions for 4 to 6 months before the uppers begin to show signs of failure -- with 80 to 85 percent of the wear life still remaining in the vulcanized bottoms. The sole stitching and heel nail failures which so quickly ruined the welt boot have been eliminated.

FIGURE 1. DMS Tropical Combat Boot. Note lack of outsole stitching or nails; "welt stitching" is false and simulated for appearance only.

FIGURE 2. DMS boot upper in place for molding on a high-pressure C.I.C. vulcanizing machine.

The DMS boot is also more comfortable to walk in than the welt boot. The one-piece rubber bottom has decreased the weight of the tropical boot by 12 ounces a pair -- from 4 pounds in the welt boot to 3 pounds, 4 ounces in the DMS. The new bottom, without the stitching and multiple components which stiffened the welt boot sole, is so flexible that it requires no breaking-in period. Traction is improved because the tread design is applicable over the entire bottom surface. In the welt boot, the cleats recede a half-inch from the sole edge to allow room for a round of sole stitching(3).

The new DMS boot is not only functionally superior to welt footwear, it is also more economical. The durable vulcanized bottoms eliminate the tremendous expense of footwear repair and maintenance. It is the Army's experience that a pair of welt combat boots required during its lifetime repairs costing more than half the initial price of the boots. This included the cost of materials, the training and labor of personnel, and the maintenance of field repair units. According to the Army's repair and maintenance division, nearly 95 percent of the welt boots it received required repairs to the bottom(4). But since the new DMS soles outlast the tropical boot uppers, the boots simply are discarded and replaced with a new pair when the uppers wear out.

The initial cost of the DMS boots averages $5 to $6 a pair less than the welt tropical boot, since vulcanized footwear can be produced cheaper and faster than welt(5). The DMS boot requires approximately 15 fewer material components than the welt boot and eliminates 38 operations, many of which required trained craftsmen. One unskilled worker can handle up to 20 vulcanizing machines and each machine has a capacity to produce 85 pairs a day on the normal 3-shift schedule.

Thus the DMS tropical boot represents a breakthrough in durability, comfort and economy for heavy duty footwear, military and civilian. This progress is the result of more than a decade of research and development at the U.S. Army Natick Laboratories (NLABS) under the Army's program to improve military footwear.

2. Welt Construction Footwear

a. Salvage Studies

The footwear development program -- which led ultimately to the DMS boot -- received its impetus from salvage studies of boots worn in World War II and the Korean War. U.S. Army Quartermaster Corps teams examined a total of more than 2000 Army combat boots and service shoes in Western Pacific salvage depots in 1946(6), and more than 19,800 combat boots and shoepacs from Korea in 1952 and 1953(7,8).

In each survey the predominant areas of failure were in the boot bottoms: broken welting or outsole stitching, loose or missing nails and heels, burned midsoles, and cracked or broken insoles (Figure 3). The Manila World War II depot repaired or replaced the soles and heels of more than 45 percent of the boots it received. Of the remaining unrepaired boots, more than 61 percent had bottom failures in the insoles, such as cracks caused by outsole nails penetrating the insole; and 30 to 33 percent showed separation of the outsole and midsole due to broken welt stitching. Obviously, the wear life of military boots was dependent on the durability of the boot bottoms.

b. Tropical Welt Footwear

Extensive efforts were made to improve stitched, welt construction boots before the Army began research on the DMS process in the mid-1950's. Tropical footwear was the primary target of research from the beginning. This was partly because it was produced in less quantity than the leather combat boot and would create less impact on industry if it were changed. More important, the tropical combat boot was the most inadequate footwear item in the supply system. Requests later by Special Forces troops in Southeast Asia for a better boot naturally intensified work on tropical footwear. The eventual attainment of a tropical boot which troops returning from Vietnam called "the best boot the Army ever issued," was doubly rewarding because tropical footwear presented the greatest challenge(9).

The issue of special military footwear for the tropics dates from World War II(10). Shortly after Pearl Harbor, the Panama Mobile Forces began patrolling jungle areas bordering the Canal Zone. It quickly became apparent that special footwear was required to withstand the heat, moisture and fungal deterioration encountered in the jungle. The leather of the standard service shoe deteriorated quickly and the leggings worn with the shoe were too hot and heavy.

The Mobile Force initiated a program with several rubber companies to develop a durable lightweight boot that would withstand jungle conditions. The Army Quartermaster Corps took over the program in its early stages. Efforts were accelerated in July 1942 when Gen. Douglas MacArthur urgently requested tropical footwear for his troops in the Southwest Pacific area. By August 1942, the first jungle boot was ready and was standardized for tropical wear. This boot was constructed somewhat like a high tennis shoe, with a canvas duck upper and a soft rubber sole (Figure 4).

Unfortunately, the jungle boot, while an improvement over the service shoe in some respects, proved grossly inadequate in others. It was lighter and dried quicker than the leather shoe and it eliminated the leggings, but troops suffered foot fatigue because of the boot's lack of foot support and soft sole. The soft rubber bottoms slipped on wet slopes and provided little protection against sharp objects and rough terrain.

In the summer of 1944, the Quartermaster Corps conducted a major field test of 300 separate tropical items during simulated jungle maneuvers at Camp Indian Bay, Florida. It concluded that none of the standard footwear tested, including the jungle boot, was satisfactory for jungle use. Test subjects never became accustomed to the lack of foot support in the canvas-upper boot, even after 21 days of wearing the boot[11].

An experimental tropical combat boot designed to correct the deficiencies of the jungle boot was included in the Camp Indian Bay trials. It was a welt boot with a hard rubber sole and heavy cleat tread for firmer support and better traction. Instead of an all-canvas upper, the new boot had a leather vamp which gave support to the lower part of the foot. The rest of the upper was made from a nylon duck, which dried quicker, felt cooler and outwore the canvas used in the jungle boots (Figure 5). In addition, two eyelets were built into the leather instep for water drainage and ventilation.

Post-war field trials of that combat boot indicated the durability of the outsole and the ankle support of the new item were inadequate[12]. Subsequent attempts to improve the welt boot included the addition of a leather eyelet stay to stiffen the upper[13]; and hardening the outsole and reinforcing the bottom with various stitching designs and more heel nails [14,15]. Even with extra sole stitching and nails, 60 percent of the welt boots failed after 40 days (250 miles) of hot-dry field wear in 1955 tests at Yuma, Arizona.

The Army seemed to have reached the limits of durability possible with stitched, welt footwear. Researchers subsequently turned to a totally different construction -- the DMS process.

FIGURE 3. Bottom of DMS tropical combat boot, left, is virtually undamaged after 6 months of wear in Vietnam. After only 10 days of similar wear, bottom of welt boot at right shows typical broken outsole stitching and torn welting.

FIGURE 4. First Army jungle boot with canvas upper, soft rubber sole.

FIGURE 5. World War II tropical combat boot with leather vamp, nylon upper.

3. Development of DMS Military Footwear

a. Existing DMS Production

When the U.S. Army Natick Laboratories (NLABS) installed a vulcanizing footwear machine in 1955 to conduct DMS research, European countries were manufacturing women's and children's shoes by the DMS process in great quantity. German and Czechoslovakian shoe firms claim to have produced the first DMS footwear in the late 1920's and early 1930's[15]. The economical new method caught on quickly during the Depression period of the 1930's, and DMS manufacturing spread to Italy, Spain, Denmark and England. Most of this footwear had soft rubber soles and fabric uppers, such as slippers or tennis shoes, and was made on low-pressure machines.

The Wellco Shoe Corporation, Waynesville, N.C., introduced vulcanized footwear in the United States during the 1940's. Other American manufacturers began producing DMS boots but the new footwear was not as readily accepted by the American public as it was in Europe. At the time the Army began investigating the process, most of the U.S. firms had dropped out of the field.

NLABS footwear technologists could draw on European knowledge only to a limited extent. Almost all DMS manufacturing at that time consisted of casual and street shoes or light boots, usually with non-leather uppers. No company had vulcanized hard sole, heavy-duty leather boots durable enough to meet military requirements. Army researchers had to adapt the DMS process and find new footwear materials before the manufacture of a DMS tropical boot would be possible.

b. DMS Research for the Tropical Boot

The equipment used in commercial DMS production was not capable of vulcanizing a military boot. Most manufacturers were vulcanizing casual shoes with soft, spongy rubber soles on low-pressure machines which delivered from 30 to 80 pounds per square inch (psi) of pressure. NLABS researchers determined that a minimum of 250 psi would be necessary to vulcanize the rubber compounds needed for the sole and heel of a military boot. This was confirmed when an attempt was made to utilize low-pressure machines for an early test production of the boot: the bond between the bottom and upper separated in many of the boots during field wear.

An American industrial capacity for quantity production of high-pressure vulcanized footwear had to be created. When NLABS began its DMS program, the only high-pressure equipment available was from England. As other machines proved capable of delivering adequate pressure, they were authorized by the Army for use by its DMS boot contractors. By 1962, six American companies had installed a total of more than 160 high-pressure machines capable of producing the DMS tropical combat boot(5).

While the machinery required to develop a satisfactory DMS military boot existed, the footwear materials did not. The rubber compound for the bottom, the leather for the boot vamp, and the bonding cement were specially developed to obtain a boot on high-pressure equipment which would meet military requirements.

The rubber bottom was expected for military needs to be durable, non-marking, resistant to oil and ozone, and tractional at low temperatures. The rubber, leather and the bond they formed also had to resist deterioration for five years of storage under unfavorable conditions. Most commercially used rubber compounds and leathers could not meet this unique storage requirement.

High-pressure molding of a boot with a leather vamp required nearly twice the cure time needed for a casual shoe with a fabric upper because only the side and base molds, and not the last itself, could be heated. The longer cure time and stiffness of the sole rubber made the balance of flow, curing time and shelf-life characteristics of the bottom compound critical(16).

The Natick Laboratories investigated a new type of polyblend nitrile rubber introduced commercially about that time(17). After months of experimentation, a compound was formulated which provided excellent durability and was resistant to gasoline, ozone and aging. This compound -- a copolymer of butadiene and acrylonitrile blended with 30 percent polyvinyl chloride for durability -- performed well under high-pressure vulcanization. To ensure acceptable, uniform bottoms, the Natick Laboratories specified the proper size and weight for the rubber biscuits.

The leather for the vamp or lower foot of the boot had to be compatible with the rubber compound: it could not contain finishes or lubricants which would preclude a strong bond with the adhesive and boot bottom. The leather also had to be capable of withstanding the high temperatures (ca. 320°F.) and high pressure of the molding process without weakening or cracking.

NLABS investigated many standard Army leathers and commercially used leathers in a wide range of tannages and compositions. The final choice was a chrome-tanned leather which was modified for the DMS process and treated for mildew resistance.

At first no effort was made to waterproof the tropical boot because soldiers constantly wetted their footwear in damp jungles, swamps and knee-deep streams. For foot comfort, it was more practical to drain water from the boot with eyelets at the instep and to use a nylon duck upper which dried quickly. However, by 1964 NLABS had examined enough of the new DMS tropical boots worn in Vietnam to observe that the leather portions required some type of water-resistant treatment.

Various treatments were investigated, including several silicones. After extensive experimentation, a silicone treatment was obtained which decreased the water absorption of the boot leather to a maximum of 30 percent of the environmental water. The treated leather dried quicker and without stiffening, and lasted longer under tropical humidity(18).

The DMS program had advanced far enough by 1958 to submit the first boots to actual wear trials. Fifty pairs were distributed locally to construction crews, mailmen, policemen and others, all of whom reported the boots were lighter, more durable and more comfortable than their standard work shoes. Early in 1959, 75 pairs of the experimental boot were sent to the Army Quartermaster testing center at Ft. Lee, Va., and 100 pairs were fitted on U.S. troops in Panama.

Guided by the findings of these first wear trials, NLABS designed three variations of the DMS boot for more extensive field tests in Panama during 1960 - 1961(19). The boots were similar in design to the welt construction tropical combat boot of World War II, which had a laced foot and buckled cuff. The three types varied only in their upper materials: an all-leather upper, an all-nylon upper and a combination leather vamp and nylon upper.

The all-leather upper DMS boots proved to be uncomfortably hot and heavy, and dried slowly. The all-nylon uppers did not provide adequate foot support or protection against external objects. The combination leather-nylon upper was the most satisfactory, and it became the basic design of subsequent tropical test boots.

The results of the Panama field trials confirmed the basic superiority of the DMS construction, although there were some bond failures. The wear life in all the DMS soles was greater than any of the uppers, and the durability of the bottom-upper bond was at least equal to that of the upper materials.

Changes were made in the boot's design and components. The buckled cuff, which snagged on undergrowth and jingled as the wearer walked was replaced by a full-laced closure. A 50/50 nylon/cotton blend with better resistance to flaming was used instead of the 100 percent nylon fabric for the upper.

The most significant improvement in the experimental boot was the attainment of a durable, reliable bond between the boot upper and bottom. A strong bond is difficult to achieve consistently because so many factors are involved, including cure time and temperature, the condition of the rubber before vulcanization, and the proper application and drying of the liquid cement on the lasted boot upper.

When the DMS boot made on low-pressure equipment was tested by the U.S. Army Infantry Board (USAIB) in Panama in 1961, nearly 57 percent of the boots showed bond failures(20). NLABS re-examined the cement being used and developed an adhesive more compatible with the rubber sole compound. A check test in 1962 by USAIB indicated the new adhesive and the use of high-pressure equipment had eliminated bond failures(21).

The new DMS tropical boot was approved for limited production by the Quartermaster General in May 1962. The demand for the boot for U.S. troops in Southeast Asia was so great that NLABS recommended the boot be classified as the standard tropical item to replace the 1944 welt tropical boot. After further check tests by the USAIB and the U.S. Army Tropic Test Center during 1964, the boot was adopted formally on January 23, 1965, for both the U.S. Army and the Marine Corps(22).

c. Spike-Protective DMS Boot

A unique spike-resistant steel innersole has been added to the DMS tropical boot since its adoption. Special Forces in Southeast Asia had received samples of experimental DMS tropical boots since August 1961. They reported a need for a special feature in the new boot that would provide protection against sharp metal or bamboo spikes which the enemy concealed on the ground or in streams. The spikes or punji stakes, often poisoned intentionally or contaminated by human excrement, could penetrate the soles of conventional boots and cause serious and even fatal injuries(2).

The initial idea was to supply an insole made of overlapping strips of steel encased in fabric which would be slipped into the DMS boot, somewhat like the insole worn with firemen's boots. Although not entirely satisfactory, the insole afforded some protection and 30,000 pairs were shipped as an interim item to Vietnam in June 1963(23).

An experimental boot was also designed with the steel strips incorporated into the outsole of the boot during the molding process. In wear tests, however, the steel strips shifted and caused gaps which left the foot vulnerable to spike injury.

NLABS technologists returned to the insert-insole, but this time using a one-piece stainless steel plate .011-inch thick. It was shaped to fit the bottom of the foot and laminated with woven plastic screening for ventilation and foot comfort. The insert increased the boot's protection by an estimated 80 percent: a minimum of 265 pounds of force at contact was required to pierce the boot sole and shield(24).

Reports from troops in Vietnam and the results of engineering tests at Ft. Lee, Va., indicated the new insole-insert was uncomfortable. The insole became hot, blistering and chaffing the feet after prolonged walking. It also required from one-half to a full-width larger boot and thus could not be worn at will with a soldier's regular issue boots.

By the fall of 1966, the Natick Laboratories devised a successful protective boot by sandwiching the steel plate between two layers of the leather insole before the bottom was molded to the upper (Figure 6). As an integral part of the boot, the new shield eliminates fitting and wear discomfort problems. The shield is also about half as expensive as supplying an insole-insert as a separate item. All DMS tropical boots sent to Southeast Asia since July 1966 have incorporated the new spike protective shield(25).

d. DMS Leather Combat Boot

By 1961 the basic problem of adapting the DMS process for the tropical boot had been solved, and NLABS began a program to apply the vulcanized sole to the leather combat boot as well. The major difference in the two boots was the wider range of environmental conditions and uses for which the leather combat boot was issued. The principal questions were the adequacy of the DMS bond at low temperatures and the traction of the sole compound and design on snow and ice.

A small sample of experimental DMS leather boots was tested in 1963 with encouraging results. During 1964-65, more than 600 pairs were subjected to wear trials by U.S. troops in Germany, Korea and Alaska(26). The first DMS leather boot demonstrated satisfactory durability and bond strength, but its sole gave poor traction on ice and snow. The rubber sole stiffened at low temperatures and the cleat tread design became clogged with snow.

FIGURE 6. Steel plate incorporated into DMS tropical boot sole protects soldiers in Vietnam from hidden punji stakes and poisoned spikes.

FIGURE 7. Cut-away view of blast protective boot showing wedge shank of aluminum honeycomb and steel.

Experimentation began to find a rubber compound which would remain soft and flexible at temperatures as low as 0°F. A styrene-butadiene compound was formulated which provided excellent traction at low temperatures and was durable and ozone resistant. NLABS also devised a new chevron tread with better self-cleaning characteristics than the cleat design used in the tropical boot sole.

The DMS leather combat boots with the new rubber compound and tread design performed satisfactorily during check tests at Ft. Lee, Va.[27]. The Army adopted the boot in January 1967 to replace the welt combat boot. The new boot may be even more economical than the DMS tropical boot: it is expected to last two to three years without repair under normal wear, and eventually to cost 20 percent less than the welt combat boot. Like the DMS tropical boot, it also is lighter than its welt counterpart and requires no breaking-in.

A one-piece leather vamp is being investigated which would raise the seam between the vamp and upper a few inches from the sole all the way around the combat boot. This feature, in conjunction with the impermeable DMS bond and the new silicone treatment, may make the all-leather DMS combat boot nearly waterproof as well as resistant to various chemical agents.

4. Potential of DMS Footwear

The DMS tropical boot marked a milestone in the history of U.S. military footwear by freeing developers from the limitations of the stitched welt construction. The DMS tropical and all-leather combat boots are only an initial tapping of the production potential created by vulcanized footwear. The DMS process makes feasible the mass production of designs and levels of foot protection which would be impossible or too expensive and slow with a stitched-bottom construction. The spike-protective steel plate -- so easily incorporated into a vulcanized boot sole -- is an example of this.

Boots which give significant protection against antipersonnel land mines are being tested in Southeast Asia[28]. With the DMS process, researchers have been able to build a honeycomb-steel shank into the sole of the tropical boot which deflects and absorbs the force of a mine explosion and decreases the extent of foot injury (Figure 7). Such protection was never possible before except with auxiliary equipment or special footwear which severely restricted mobility.

Another research project is to lighten the DMS boots by a pound a pair. Since nearly 70 percent of a boot's weight is in its sole and heel, NLABS is working with industry on a new rubber compound for the DMS boot bottom. A microcellular rubber is being investigated which is less than half the weight of the present sole compounds. Although microcellular rubber is used extensively in casual shoes, it must be adapted for the DMS process and further developed to increase its durability for military use.

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13. ABSTRACT

The U.S. Army Natick Laboratories have modified a method of footwear construction known as Direct Molded Sole (DMS) for the Army's tropical and all-leather combat boots. NLABS developed the special component materials, boot designs and fabrication techniques required to produce military footwear by the DMS process. The sole and heel of the new DMS boots are molded directly to the boot uppers on high-pressure vulcanizing machines, eliminating the sole stitching and heel nailing which were the major points of failure in welt combat footwear. The DMS boots are significantly more durable and more comfortable than welt construction boots, and will save the military money both in production cost and by reducing boot repair and maintenance problems. The DMS process has enabled NLABS to incorporate special protective features into the tropical combat boot, including a steel shield to resist penetration of the boot bottom by punji stakes, and a wedge shank to deflect and absorb the impulse of antipersonnel land mines.

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Protective footwear	4		8,10			
Military requirements	4					
Protection			8			
Foot			9			
Military personnel			9			
Shanks			8,10			
Steel			8,10			
Honeycomb			8,10			
Metal plates			8,10			