AMMUNITION LOADING TECHNIQUES

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INTRODUCTION

1. In general, two methods of loading explosives into ammunition are in use, first, casting (referred to as melt-loading) and secondly pressing, or consolidation by means of pneumatic or hydraulic presses. The latter is used for loading detonators, and making small pellets for boosters, and also for loading shell with explosives which have melting temperatures too high to make melt-loading feasible. The former method, casting, is usually the more economical of the two, and is used as universally as possible. The bulk of this report deals with melt-loading.

2. All standard present day melt-loaded explosives melt at a temperature of about 176°F (80°C). However, the optimum casting or loading temperature for most of these explosives ranges from about 1°C to 10°C above the melting temperature. All castable explosives shrink upon changing from the liquid to the solid state. Therefore, whenever possible, provision must be made to supply a reservoir or riser of molten explosive above the loading opening in the item. This riser will then supply additional molten explosive to the main charge in the item to fill up any shrinkage cavitation which may have occurred during the initial charge solidification.

DISCUSSION

3. <u>One-Increment Loading Technique</u>

a. Probably the most widely used loading technique is the one referred to as "One-Increment Loading". In one-increment loading, a riser usually in the shape of a funnel is inserted into the loading opening in the item and the explosive poured in a thin continuous stream (about ½ inch diameter) along the inside wall of the funnel, until the explosive has reached a level about ½ inch from the top of the funnel. If Composition B, 50/50 Pentolite, 50/50 Amatol, HBX, or Torpex is being used, the optimum pouring temperature is about 86°C. The optimum pouring temperature for 70/30 Tritonal is about 82°C. TNT, because of the large amount of shrinkage when changing from the liquid to the solid state is normally poured as a slurry or mush having a temperature of about 80 °C. Normally, items as large as a 120mm HE shell (about 7½ lbs of explosive) can be poured using this procedure, depending upon the internal shape of the item being loaded and the specific explosive being used. Since nearly all the castable explosives are similar in physical properties to either Composition B or TNT, the remainder of this report will deal mainly with the loading of these two explosives. The reason for this is that a loading procedure applicable to either of these two explosives will be applicable to the remaining castable explosives. When using Composition B, the one increment loading procedure can be used very successfully for items as large as the 120mm HE shell. In the case of TNT, normally, only shell charges about as large as that of a 90mm shell can be cast successfully.

b. In order to load millions of pieces of ammunition, time must be considered and man-power replaced by machines. The one increment loading technique is very adaptable to mechanization. In production, a multiple pour machine, commonly called the "mechanical cow" is used. This machine consists of a stainless steel box containing an inlet, an outlet, and 60 partitioned cubicles, and is equipped with vacuum lines. Each cubicle has a hole in the bottom closed by a neoprene stopper. The machine is also equipped for maintaining a constant temperature. The operator actuates a lever on the vacuum draw system to fill the box and cubicles. When the desired level of explosive is attained, the vacuum is shut off and all excess explosive flows, by gravity, back into the holding reservoir. The machine operation actuates another lever removing the neoprene stoppers permitting a steady stream to flow into each of 60 shell spotted under the openings in the 60 cubicles. Each cubicle holds the correct volume of explosive to fill a shell and funnel. The shell are then put in a cooling bay until cool enough to allow removal of the funnels.

c. At this point it should be mentioned that in pouring explosives, regardless of what they may be, all splashing of explosive is to be avoided since splashing in the shell will result in entrapment of air bubbles within the cast, perhaps rendering the charge unacceptable from a cavitation standpoint.

4. <u>Multiple-Increment Loading Technique</u>

In order to cast larger charges than the 120mm in the case of Composition B, a two-increment or perhaps three-increment loading procedure may be used. These procedures are the same as the one-increment, except that rather than filling the item in one pour, the item is only partially filled with explosive. After a short waiting period, to allow some cooling and shrinkage of the first pour, accompanied by breaking of any crust formed on the top of the explosive, a second pour is made, etc. It has been found that for shell calibers between 120mm and 155mm in size (8 to 15 lbs) two increments are necessary, while for larger items three increments are needed

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in order to minimize cavitation.

5. Core Melting Loading Technique

In the case of TNT loadings, larger than about a 90mm shell another variation of the "Increment" loading technique is used. The procedure is known as the "Core Melting" procedure. The shrinkage of TNT from the liquid to the solid state is considerably more than that of Composition B, amounting to about 4% for Composition B and about 9% for TNT on a volumetric basis. By pouring TNT as a slurry consisting of about 30% solids, the shrinkage of a cast is reduced; however, corrective action to eliminate cavitation is normally still required. In the Core Melting Procedure, the item to be loaded is filled using a one increment pour. During solidification of the charge, a centrally located, longitudinal cavity is formed. By remelting the core of the charge with a metal steam-heated probe about one inch in diameter, this pipe-like cavity is removed. TNT melts at the rate of about 3 inches per minute under these conditions. Normally the TNT core is melted only to the depth of this cavitation. After the hot probe is made, mush-consistency TNT is poured into the shell and funnel until the level is again about ½ inch from the top of the funnel. The various pouring consistencies are shown on the inclosed Table 1. A one-probe technique is adequate for TNT-loaded items up to about a 120mm caliber shell (approximately 7.5 lbs charge). For shell up to about 155mm caliber it is necessary to use the hot probes twice with filling and solidification in between, the depth of the first probe being about 14 inches from the top of the shell and the depth of the second probe being 6 inches. For larger shell such as 8-inch or 240mm HE shell, hot-probing three times is necessary to eliminate the cavitation.

6. Composition B Hot Probe Technique

A modification of the Core Melting Technique for loading TNT is the "Hot Probe" technique for Composition B. As previously mentioned, with the use of steam-heated hot probes, a solid TNT cast can be melted at the rate of about 3 inches per minute. On the other hand, a Composition B cast will melt at the rate of about 1/30 inch per minute - consequently, the "Core Melting" technique would be too slow to be practical for Composition B. In the Hot Probe technique, the hot probe or hot finger is inserted into the explosive charge immediately after pouring, while the Composition B is still molten, to a depth about level with the bottom of the funnel. In this way as the main charge solidifies, the riser or funnel throat and loading opening in the item are kept open by the hot steam-heated probe so that any piping cavitation is immediately filled by the liquid reservoir of the explosive in the funnel. The hot probe is allowed to remain in the item for a length of time dependent upon the size of the casting. In the larger items it may be necessary to replenish the molten explosive in the riser from time to time as the main charge solidification takes place. For specific items, variations such as different probe depths, probe time in item, and steam temperatures may be made. This loading procedure is not as widely used as the One-Increment and Core Melting Loading procedures.

7. Single Pour - Controlled Cooling Loading Technique

a. The next loading technique which will be discussed is the Single Pour - Controlled Cooling (SPCC) Technique. This procedure has been developed to a fairly refined stage at Iowa Ordnance Plant, and has had limited use for production loading of 155mm M101 HE shell with TNT. In this loading procedure, like the preceding ones, a funnel or riser is placed in the loading opening of the item to be loaded and explosive poured into the assembly to within about ½ inch from the top of the funnel in one continuous pour. The melt kettle is connected with a vacuum system and explosive is deaerated prior to pouring. As the explosive melts on steam-heated grids and drips into the bottom of the melt kettle, the air dissolved within it is withdrawn. After the shell is filled, as the name of the procedure implies, the cooling of the explosive charge and shell is closely controlled over a period of many hours. The cooling of the bottom part of the shell is accelerated by placing the shell in a cool water bath, while the topmost sections of the shell and funnel are surrounded by hot air at a temperature considerably above that of the melting point of the explosive. Charges produced by this loading procedure are almost always more dense, more homogenous, and cavity free. A typical data sheet enumerating the loading conditions for some HE shell is inclosed as Table II. In the table, Radiant Oven No. 5 is one of the various designs of oven used in this technique. This particular design incorporates the use of steam-heated copper tubes inclosed within a funnel-shaped aluminum sheet and surrounded by an aluminum reflector. The steam pressure of 50 psig shown in the last column on the table is that of the steam within the copper tubes. As seen from the footnote in Table II, the 50 psig steam pressure results in a temperature of 200°F on the funnel surfaces. This is about 25°F above the melting temperature of TNT.

b. Although the SPCC method of loading shows great promise, in that high quality casts are produced, the cost of new equipment, and slightly increased costs of loading have prevented its full utilization throughout the loading plants for all Ordnance items. For loading large caliber shell, or other items of ammunition in which high quality casts are required, the SPCC procedure has been proven as the most efficient and economical loading procedure.

8. Pellet Loading (Puddling) Technique

The next loading procedure which will be discussed is that known as "Pellet Loading" or "Puddling". This loading procedure can be utilized with either TNT or Composition B type explosives and is normally used for loading only large ammunition items such as large bombs, mines, warheads or bare charges. In this loading procedure, pellets or chunks of explosive must be prepared prior to loading the item. These chunks, about 3/4 inch by 1 inch by 1 inch are manufactured in conductive-rubber ice-cube like trays or else slabs of the explosive are broken up into chunks using a rubber or wooden mallet. Normally about 30% of a pellet-loaded charge would consist of pellets. The loading procedure itself consists of pouring a few inches of molten explosive into the item and placing the pellets as close together as possible, sumerged in the molten explosive. Pellets or chunks are added until they reach to within about 1/8 inch from the top of the molten explosive level, then another few inches of molten explosive are added. The process is continued until the item is completely loaded. Although this loading procedure is slow and tedious, and results in a rather poor quality cast, it has the advantage of producing an item which can be handled and transported immediately after the loading is completed, since the item is more or less cooled by the pellets as the loading procedure progresses. As mentioned previously, this loading procedure is used only for the loading of large items such as bombs, warheads, etc, which do not have strict cavitation limits but which are merely passable on a minimum charge weight requirement. In general, items loaded by this procedure are those which are dropped from planes, launched at low setback, or remain stationary prior to performing.

9. The "Sit and Simmer" Technique

In an attempt to place the Pellet Loading or Puddling Technique on a production scale, during World War II, a combination one-increment, pellet loading technique called the "Sit and Simmer Technique" was used for loading large bombs. This procedure consisted in filling the bomb in one continuous pour and allowing it to "sit and simmer" for a period of time. This waiting period varied for different bombs but was predetermined so that the next operation was made when the central portion of the charge was still in a molten state. After the waiting period, the crust which had formed on the top of this explosive charge was broken, and pellets, of the type described under pellet loading, placed in the liquid and air space uncovered by the broken crust. More molten explosive was then added until the bomb was filled to the proper level. Using this procedure greatly increased production using the same amount of manhours. The quality of the charge produced, probably was slightly inferior to that which is obtained by pellet loading as to cavitation. However, it still was acceptable under the standards in use at the time.

10. Centrifugal Casting Technique

a. This Section has conducted an investigation (see PATR 2381) of the centrifugal casting of Composition B. For this prupose a machine was designed and manufactured capable of loading two 57mm HEAT T188E10 HEAT shell at a time, at various rates of spin. In this machine, the shell and risers were assembled and filled in a vertical position. The arm of the machine was then rotated, and the cradles holding the shell assemblies were swung outward to a horizontal position by centrifugal force. They remained horizontal for the duration of rotation.

b. The investigation showed that satisfactory casts could be made by this technique. The major variation in the charge properties induced by this method was a greater amount of segregation of RDX crystals, that is the percentage of RDX in the overall cast was greater, especially at the bottom.

c. Although this technique was proven to produce satisfactory crusts, no advantage in penetration was evident from HEAT shell loaded by this technique. Accordingly, this method of loading has not been investigated further.

11. Jolting Loading Technique

Another loading technique which has found application at this Arsenal on a production basis is a procedure involving a jolting motion. Although possibly applicable to loading other Ordnance items, this procedure was developed solely for the T37E4 (M31) 2.75-inch rifle grenade. During experimental loadings of this item, it was found that in static test firings, the 11-inch required penetration of mild steel plate could not be met consistently. An investigation showed that because of the sharp angle of the shaped charge within this grenade, small air bubbles were entrapped between the base of the cone and sidewall of the item resulting in reduced penetration. The only way that the 11-inch penetration could be met consistently was to remove the entrapped air bubbles. This was accomplished by using a Syntron Jolting Machine motivated by compressed air. The loading procedure consists in preheating the bottom half of the rifle grenade in hot water (about 90°C) then pouring the Composition B filler in one increment to about 1 inch from the top of the attached funnel. The grenade is then placed in a rack which, in turn, is placed on top of the jolter. It is jolted for about 10 seconds at the rate of about two jolts per second, removed from the jolter and allowed to cool to room temperature.

12. Vibration Loading Technique

A variation of the jolting principle is the use of vibrating table. Some experiments have been run using a Baldwin Oscillator producing a sinusoidal motion, however, even though vibration loading of 90mm M71 Composition B-loaded shell for different lengths of time at various rates of vibration has resulted in acceptable casts, no improvement over the one increment loading technique as to cast quality was obtained. On the other hand, in the casting of viscous explosives in which air bubbles would normally be trapped if no vibration were used, the vibrating of the item during pouring or immediately after pouring, has helped greatly in eliminating entrapment of air bubbles. In cases such as this, the use of vibration loading could be a tremendous aid in cast loading a large number of ordnance items.

13. Moulded TNT Loading Technique

a. The last cast-loading method discussed here is a European loading technique used in Belgium on a wide scale and known as the Moulded TNT Loading Technique, or the TNT Loading Method of Solid Cores. As the title suggests, this method is used for loading TNT only, at the present time. According to the Belgian ammunition manufacturers, cavity-free, homogeneous, high-density, casts are produced. The loading procedure has never been attempted in this country although examination of casts from Belgian 3-inch shell casts examined at this Arsenal has borne out the Belgian claims. The loading procedure involved in loading this shell consists in pouring molten TNT at about 80°C into the shell, filling about 15% of the shell cavity. A shaped core of solid TNT is then placed into the molten TNT until the bottom of the core touches the inside bottom of the shell. The core is held in place for about 10 seconds by a centering machine while the molten TNT hardens enough to support the core in an upright position. The centering machine is then withdrawn and the rest of the shell cavity is filled with molten TNT.

b. The TNT core or "carrotte" used in this procedure is made by individually pressing very small increments of molten TNT in a water-cooled cylinder, with a water-cooled conical-pointed piston. The piston descends slowly into the molten TNT, which crystallizes instantly against the cold walls of the piston. The piston continues to descend until the thickness of the deposited solid TNT is about 1 millimeter. The piston then returns to its original position while more TNT is added. This operation, repeated about five times per minute produces a solid, cylindrical molded rod.

14. <u>Press-Loading and Its Uses</u>

The final loading procedure to be discussed will be that of press-loading. Press-loading is utilized to the greatest degree by the Army in pressing primer, delay, relay and detonator compositions for fuze components, various size pellets for other ammunition components and incendiary charges for shell. Explosives such as Composition A-3, Composition C-4, Explosive D and MOX 2 B are the most common pressed shell fillers. In the smaller calibers of shell up to about 30mm, press-loading is almost always used. For HEP shell, press-loading of Composition A-3 is widespread. The pressing of Explosive D in shell designed to explode after penetrating armor plate (Armor-Piercing and Semi Armor-Piercing) is also widely used. Naval Ordnance loading plants use press-loading techniques to a much greater extent than Army plants since Composition A-3 cannot be cast loaded and this type of explosive fits their needs more fully than equally brisant cast explosives. Presently the trend in Naval ammunition loading is toward developing castable fillers of the Composition B type. Press-loading procedures may vary somewhat for special applications, but, in general, the procedure consists of adding an increment of loose, granular explosive into the shell or mold and pressing the increment at a predetermined pressure at a slow rate of ram travel. Normally, a few seconds dwell time is allowed in order to obtain a more uniform density throughout the increment. Another increment is then added and the pressing operation repeated, until the item is filled. The pressures used vary for the various applications, varying from about 1200 psi for Composition C-4 pressings to about 30,000 psi for MOX 2 B loading of 20mm shell.

15. <u>Finishing Operations</u>

In all loading operations, after the item is full, a certain amount of finishing is necessary. Drilling or smoothing of a fuze cavity, thread cleaning, and some stencilling operations necessarily follow the loading operation before the job is complete.

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TABLE I

CONDITION OF TNT FOR POURING

TNT may be poured in various conditions to obtain different results. The proper pouring condition will depend upon the properties desired. At the transition point the temperature will be constant, but as the heat of crystallization is dissipated the TNT becomes less fluid and more crystallization takes place. The following definitions cover the various stages or conditions of TNT which may be required for pouring.

Hot TNT: A clear liquid ranging in color from a red to a red brown. No crystals are present and material is very fluid. Temperature of hot TNT will be above the melting point.

Hot Gold Flake: A clear liquid TNT containing some widely separated short needle like crystals distributed throughout mass. These crystals when viewed in a good light reflect light like small flakes of gold leaf.

Medium Gold Flake: A clear liquid TNT containing a large quantity of crystals throughout mass.

Cold Gold Flake: A slightly cloudy material containing a large quantity of crystals and crystalline agglomerates.

Translucent: A very cloudy, semi-transparent material containing a heavy mass of crystals and crystalline agglomerates. TNT in this condition is not as fluid as clear TNT.

Thin Mush: A heavy mass of crystals, completely opaque with no streaks of melted TNT apparent, yet quite fluid and smooth flowing. It can be compared with thin applesauce in appearance.

Medium Mush: A heavy mass of crystals, completely opaque, with no streaks of melted TNT apparent. It is thicker and heavier than thin mush and only moderately fluid. It just resists breaking as it flows and appears quite grainy.

Heavy Mush: A very heavy mass of crystals, completely opaque with no streaks of melted TNT apparent. Material is no longer fluid and will not pour smoothly, it is a very heavy semi-fluid material which breaks as it pours.

TABLE I (Cont)

With the exception of Hot TNT, the temperature of all the stages is the same, and is that of the freezing or transition point, 174° - $176^{\circ}F$, consequently the temperature is not a reliable or workable criterion of the proper condition of the TNT.

TABLE II

TYPICAL OPERATING CONDITIONS AND COOLING CYCLE TIMES FOR LOADING HE SHELL BY THE SPCC METHOD

Round	Total Cycle Time (hr)	Oven #5 on (hr)	Oven #5 off (hr)	Water Temp °F	Water Level Inches	Steam Pressure psig
155mm*	5-½	4-½	1	75	10	50
155mm**	5-½	5-½	0	120	10 for 2-½ hrs 8 for 1 hr 6 for 1 hr 4 for 1 hr	50
8 inch*	10-½	9	1-½	70	12 for 7 hrs 9 for 3-½ hrs	50
4.2 inch*	3	2	1	75	5	50
105mm**	3	2	1	75	5	50
105mm**	3-½	2-½	1	120	5	50
75mm**	1-¼	½	3/4	120	5	50

* TNT loaded
** Composition B loaded

In all cases the shell obtained by the procedure listed were of uniform, high density, (1.625 ± 0.005 g/cc for TNT; 1.720 ± 0.010 g/cc for Composition B), cavity free and fine textured.

The steam pressures listed result in a temperature of 200°F on the funnel surfaces.