HISTORY OF THE DEVELOPMENT OF BALL PROPELLANT FOR SMALL ARMS

By M.E. Levy

Inception to 1945

Ball propellant, the most important development in the field of military small arms propellants since 1940, originated as a by-product of an investigation into better methods of nitrocellulose purification. The discovery of nitrocellulose by Christian Schonbein in l846 paved the way for the development of smokeless propellant. However, efforts to use nitrocellulose as propellant resulted in failure as the need for purification (and stabilization) of nitrocellulose was not recognized. In 1865, Frederick Abel, a British chemist, determined the cause of chemical instability of nitrocellulose to be the acid remaining in the fiber after nitration. By extended treatment of the fibrous materiel, heating, and the use of boiling washing water, he succeeded in washing away the residual acid, resulting in a stable material. In 1884, applying the methods of Abel to obtain purification, Paul Vielle, of France, developed the first extruded single base rifle propellant. While this method yielded chemically stable nitrocellulose, the extended time required for purification was a disadvantage. In 1930, Dr Fred Olsen reported a unique method of nitrocellulose purification, which involved dissolving nitrocellulose in a suitable solvent and then removing the absorbed acid. This method not only considerably shortened the time required for purification but also resulted in a product of greater chemical stability than previously attained. These studies led to the development of what is now known as ball propellant. During the 1930's, considerable effort was put into the development of this propellant by Western Cartridge Company (presently Olin Mathieson Chemical Corporation).

Before discussing the military applications of ball propellant, it may be well to describe briefly the conventional graining process so as to permit full comprehension of past and current developments in this field. Fibrous nitrocellulose, blended to the desired nitrogen content in a water slurry, is pumped into a vessel to which a solvent (ethyl acetate), stabilizer (diphenylamine), and a neutralizer (calcium carbonate) are added. Under controlled conditions of temperature and agitation the resulting viscous lacquer is broken down into small globules of the desired size. (Prior to breakdown, a protective colloid is added to prevent coalescence of the particles.) To remove water from these globules a salt (sodium sulfate) is added, and after the required time the ethyl acetate is removed by distillation. After the spheres are washed, they are separated into narrow granulation cuts by passing over screens. A known weight of the desired cut is then pumped in a water slurry into another vessel where nitroglycerin impregnation and deterrent coating are carried out under controlled conditions of temperature and agitation. If rolling is desired, the resulting spheres are passed through rolls while in a water slurry, and rolled to the desired web. Following drying, the propellant may be surface-coated with flash inhibiting salts and antifouling agents, if desired. This is then followed by graphite glazing, dry screening, and finally blending.

Commercial production of ball propellant started in 1933. However, it was not until 1940, when the British Purchasing Commission requested production of British .303 alternate propellant, that ball propellant was adopted for military usage. During the early years of production, reworked low nitrogen content nitrocellulose (12.1 to 12.8 percent) was used. To compensate for this low nitrogen content (and low impetus), nitroglycerin concentrations in the range of 15 to 20 percent were used. The deterrent coating applied to these propellants was diphenyl phthalate. When procurement of large quantities of new nitrocellulose became possible (approximately 1943), the reworked material was abandoned. Since the criterion of acceptance was solely the meeting of ballistic specifications, the variation in composition was disregarded.

Machine gun tests revealed the .303 ball propellant produced considerably less flash than did the standard cordite propellant. Production requirements for this type propellant were completely filled by 1944.

A substantial amount of ball propellant was produced for the caliber .30 round during the WW2. In 1944, ball propellant was approved as the substitute standard for Caliber .30 Ball ammunition.(1) While the ball propellant produced met the ballistic specifications for the Ball round, it could not do so with AP ammunition. The composition of this propellant was similar to that produced for the British .303 ammunition.

Starting in 1942, large quantities of ball propellant were produced for Chinese 7.92mm ammunition. The propellant originally developed was based upon reworked nitrocellulose and had a composition similar to the .303 propellant. However, the type developed with new nitrocellulose (when it became available in 1943) corresponded closely to the current conventional energy ball propellant. As with the .303, acceptance was based solely upon ballistic performance, so the composition variation was disregarded. Considerable flash was obtained with this propellant; however, this was subsequently decreased (1946) by slight modification of the propellant characteristics.

Small samples of ball propellant for the 20mm Oerlikon and 37mm rounds were made early in the war years, but these were largely experimental items.

The development of the Caliber .30 Carbine resulted in the need for a propellant capable of meeting the established ballistic specifications for this weapon. A ball propellant was developed for this round and production was begun in 1943. The major share of carbine ammunition produced during the war was loaded with ball propellant. In 1944, ball propellant was approved as standard for loading of carbine ammunition.(1)

A ball propellant for the caliber .45 cartridge was also produced, but on a limited scale. In 1944 ball propellant was adopted as a substitute standard for Caliber .45 ammunition.(1)

Thus, by war end of World War II, while substantial production of smaller caliber propellants had been accomplished, very little work had been done on larger calibers.

1945 to 1950

During the years immediately following World War II (1945 to 1950), ball propellant for military purposes was produced by Western Cartridge Company on a pilot plant scale, with no large production orders being placed. Working in conjunction with the Ordnance Corps, an extensive cooperative program for the development of improved ball propellant for military small arms ammunition was initiated in 1947. Under this program, substantial improvement in the performance of Caliber .30 ball propellant was accomplished, as well as the development of the Caliber .50 ball propellant. These investigations provided the framework upon which the present day development of ball propellant is based.

In 1948, a ball propellant was developed for the Caliber .30 Lightweight Rifle Cartridge which yielded a projectile velocity approximately 200 f/s greater than that obtained with the single base IMR propellant, due primarily to a higher loading density.

Further development studies(2) of a propellant for the Lightweight Rifle Cartridge were conducted, with the ultimate goal being an increase in propellant potential through the use of higher energy constituents than those employed, in conventional energy propellants. These constituents included higher nitrogen content nitrocellulose, increased nitroglycerin, and RDX (cyclotrimethylenetrinitramine). This development program was under the supervision of Office, Chief of Ordnance. However, technical supervision of all subsequent contracts was assigned to the Pitman-Dunn Laboratories Group of Frankford Arsenal. In the series of research and development contracts that followed, ball propellants were developed for Caliber .60, 20mm, 27mm, and 30mm rounds.

An improved Caliber .30 ball propellant was developed which differed considerably from that manufactured during World War II, having a nitrocellulose nitrogen content of 13.2 percent, nitroglycerin concentration of 10 percent, and a deterrent coating of dibutyl phthalate. While suitable propellants were developed for both the Caliber .30 Ball and AP rounds, they were not interchangeable. Thus, the problem, of developing a universal Caliber .30 ball propellant still existed by 1950.

The Caliber .50 ball propellant, also developed in the latter part of this period, was unique in that it was based upon an 0.034 in./0.025 in. granulation. All previous ball propellants were from 0.025 in./0.020 in. granulations or smaller. Extensive research on processing techniques was first conducted to permit obtaining economical yields of this larger granulation. It is this increase in granulation that permitted the subsequent development of ball propellant for larger caliber weapons, such as caliber .60, 20mm, and 30mm.

Studies were also conducted on the development of ball propellants for other rounds. Ballistic tests in the Caliber .45 round, conducted in 1949, revealed the standard IMR exhibited a slight superiority over ball propellant. Ballistic tests of a ball propellant developed for the Caliber .30 Blank cartridge revealed it to be superior to the Hercules EC extruded propellant in regard to fouling.

Not until 1949 and 1950 were the extremely low gun barrel erosion characteristics of ball propellant (relative to IMR) first noted. It is probably this factor, more than any other, that caused the Ordnance Corps to intensify development of ball propellant charges for all small arms.

1950 to 1956

This period may be described as one in which:

(1) The extremely low barrel erosion properties of ball propellant (relative to IMR) were noted.
(2) Ball propellant charges were developed for all small arms from a universal Caliber .30 to 30mm.
(3) The mechanical graining method for ball propellant production was developed.
(4) Large scale production of ball propellant was renewed.

While erosion is ever-present, high cyclic rate of fire weapons intensify this process. Excessive rates of erosion in machine gun barrels led to the development of stellite liners and chronium-plating of barrels in 1945. These lined and plated barrels were found to be much more resistant to erosion than the standard steel barrels. Until the discovery of the low erosion properties of ball propellant, the approach to increased barrel life was dominantly metallurgical, being directed toward improvement in the wear resistance of the barrel. Extensive erosion tests of ball and IMR propellant have been conducted at Aberdeen Proving Ground, with the criteria for barrel life being defined as: (l) a velocity decrease of 200 f/s or greater from the average of the first burst, or (2) excessive yaw in which 20 percent or more of the rounds of any burst exhibit yaw of 15 degrees or greater. Earlier definition of "excessive yaw was somewhat vague, but in recent years the above criterion has been used.

By 1950 barrel erosion tests (3, 4) were conducted at Aberdeen Proving Ground which demonstrated that both Caliber .50 and .30 ball propellants produced less barrel erosion than did the corresponding IMR extruded propellants. This performance aroused Ordnance interest and resulted in the placing of production orders, in 1951, for these propellant types. After extensive evaluation tests, ball propellant was accepted as the preferred propellant for loading of caliber .50 ammunition. While it matches IMR in all other respects, ball propellant produces substantially longer barrel life than the extruded type, as shown by the following erosion tests.

It was also found that ball propellant permitted a longer burst without cook-off than did the IMR propellant.

Schedule	Barrel	Prop.	Rounds to Vel Life	Rounds to Yaw Life
400-round burst, complete cooling after each brust				
	Lined	Ball	2300	
	Lined	IMR	800	
	Lined	Ball		8600
	Lined	IMR		388
	Unlined	Ball		3000
	Unlined	IMR		365
	Lined	Ball		9,970 (barrel burst)
	Lined	IMR		400

One of the major accomplishments in the smaller calibers during this period was the development of a universal Caliber .30 ball propellant. While ball propellants had previously been developed for both the Caliber .30 Ball and AP rounds, they were not interchangeable, due to the different speed requirements for the two cartridges. The usage of two individual Caliber .30 ball propellants not desirable as it introduced logistic problems. In 1953, a "web salt coating technique" was developed by Olin Mathieson Chemical Corporation to reduce muzzle flash noted with these propellants. The method involves essentially the application of finely ground potassium nitrate which adheres to the grain surfaces. It was subsequently found that the coating not only reduced flash, but also improved ignition characteristics of the propellant, giving better performance reproducibility. This soon led to the development of the universal Caliber .30 ball propellant capable of meeting specifications for all the Caliber .30 rounds. This type went into production in 1954, with ball propellant being designated the preferred, propellant for loading Caliber .30 ammunition.(8) The salt coating technique also aided in the development of ball propellants for other rounds, since salt coatings may also be used to modify the ballistic properties of the propellant, as required.

Caliber .30 erosion tests revealed that ball propellant yielded slightly better barrel life than IMR in steel barrels. However, with lined and plated barrels, the erosion life obtained with the former was substantially longer than that of the IMR. This is illustrated by the following results.(9, 10)

. . . . Rounds to

Schedule	Barrel	Propellant	Velocity Life	Yaw Life
300-round bursts with 2-minute intervals				
	Steel	Ball		1322
		IMR		937
	Plated	Ball		1853
		IMR		1321
	Lined and plated	Ball		4987
		IMR		1904
	Nitrided	Ball		2534
		IMR		1252

Cook-off tests revealed that ball propellant permitted a longer burst without cook-off than did the IMR.

Functioning and erosion tests of the conventional energy ball propellant developed for the Caliber .30 Lightweight Rifle Cartridge were conducted in 1953.(11) The results may be summarized as follows.

		Rounds to	
Schedule	Propellant	Velocity Life	Yaw Life
T65			
300-round bursts	Ball	1725	1725
with 2-minute	Ball, Hi E		1725
intervals	IMR	3900	3900
T66			
300-round bursts	Ball		2880
with 2-minute	Ball, Hi E		1179
intervals	IMR	1966	1966

While the effect of the gun played an important part in these tests, the data does indicate the IMR and conventional energy ball are fairly comparable in regard to erosion life. The absence of any significant improvement in erosion life obtained with ball propellant in this round may be due to its flame temperature, which is substantially higher than those of the ball propellants developed for larger caliber rounds. The relationship between propellant flame temperature and barrel life is described later in this report. The high energy ball propellant (which consisted of 13.4 percent nitrogen nitrocellulose, nominal 20 percent nitroglycerin, deterred with ethyl centralite) was developed under the series of investigations directed towards higher velocities.

A substantial amount of metal fouling was deposited on the bore by the ammunition containing ball propellant. Since most of the barrel life failures with hall propellant were due to excessive yaw, it was thought that failure was attributable more to the effects of fouling than erosion and it was therefore recommended that antifouling additives be incorporated in Caliber .30 Lightweight Rifle ball propellants.

The IMR propellant was found to produce slightly less flash than the conventional energy ball propellant, with the high energy type yielding the greatest flash.

In 1951, ball propellant was adopted as the preferred propellant for the Caliber .30 Blank cartridge. The propellant developed is cleaner and less hygroscopic than the corresponding Hercules EG propellant. Evaluation tests revealed the ball propellant produced less fouling and fewer gun stoppages than the EC type.

As a result of the large production orders placed for ball propellant after 1950, a manufacturing plant was constructed at the Badger Ordnance Works and has recently gone into operation [Production started in 1955, by 1977, Badger was mothballed. By 2004, was permanently closed.]. Production at this plant is based on the conventional graining techniques. This method, however, has certain limitations, e.g. the process yields a wide granulation spread, with the maximum granulation which can be economically produced being limited to the 0.034 in./0.025 inch cut. To overcome these difficulties, a mechanical graining technique was developed(13) which permits the production of larger grain diameters and narrower granulation spreads than heretofore attained. Pilot plant production has been conducted, and a large production plant for mechanical graining is presently being constructed at East Alton, Illinois (Olin Corp). The advantages of mechanical graining mean it may ultimately replace conventional graining for production of ball propellant. The larger granulations obtained with mechanical graining also point the way to development of ball propellants for artillery.

The superior performance of ball propellant in the erosion tests of 1949 and I950 (Calibers .30 and .50), probably coupled with the onset of the Korean War, led the Ordnance Corps to negotiate contracts with Olin Mathieson Chemical Corporation calling for the development of ball propellants for all small arms. In addition, a continuing series of contracts was negotiated to provide for increased projectile velocities through the use of higher impetus constituents. The program concerning research end development of ball propellants for small arms has been under the technical supervision of the Pitman-Dunn Laboratories Group of Frankford Arsenal. Under this program, ball propellants were successfully developed for all sma11 arms rounds. Wherever erosion tests were conducted with the larger caliber propellants developed, it was found that ball propellant was substantially superior to the corresponding IMR type. Following is a discussion of the different research and development studies conducted under this program.

Increased Velocities (14, 15, 16, 17)

In an effort to obtain small arms propellants yielding higher projectile velocities, investigation into the use of higher energy ingredients, e.g., high nitrogen nitrocellulose, increased nitroglycerin and RDX (cyclotrimethylenetrinitramine), were undertaken. (The conventional ball propellant consists of 13.2 percent nitrogen nitrocellulose and 8 to 10 percent nitroglycerin. Required ballistics for different rounds are obtained by varying the dibutyl phthalate deterrent concentration, salt coating, and the physical form of the propellant.) This series was originally designed to provide for an increase in projectile velocity for the Caliber .30 Lightweight Rifle Cartridge. However, the scope was subsequently enlarged to cover the general field of small arms. Laboratory and pilot plant processes were developed for a high energy ball propellant consisting of 13.4 percent nitrogen nitrocellulose, 20 percent nitroglycerin, and deterrent coated with 6 percent ethyl centralite. (This composition had been previously defined under Contract W-23-072-QRD-2168.) Velocities of the order of 3000 f/s were obtained with this propellant in the Caliber .30 Lightweight Rifle Cartridge, approximately 200 f/s greater than those obtained with the conventional energy ball propellant. However, accelerated storage stability tests at l00 degrees F showed this propellant type to exhibit considerable ballistic instability, yielding substantially greater pressure increases under storage conditions than were obtained with either the conventional energy ball or IMR propellant. Microscopic and chemical studies indicated this change in ballistic performance to be due to migration of one of the constituents, presumably the deterrent diffusing deeper into the grain.

Processing conditions were subsequently defined for a series of high energy ball propellants, and samples were developed which contained 13.4, 13.6, and 13.9 percent nitrogen nitrocellulose, 15 and 20 percent nitroglycerin, and 18 and 50 percent finely divided RDX incorporated in a nitrocellulose matrix. These systems were successfully deterrent-coated with dibutyl phthalate, diisobutyl phthalate, and ethyl centralite. Use of the 13.4 and 13.6 percent nitrogen nitrocellulose at the 15 and 20 percent nitroglycerin levels yielded velocity increases of approximately 200 f/s in the Caliber .30 Lightweight Rifle Cartridge and 160 f/s in the Caliber .50 round. Velocity increases of 100 f/s have been obtained in the Caliber .50, Caliber .30 Lightweight Rifle Cartridge, and Caliber .30 rounds with the 50 percent RDX propellant. While the velocity increases for the 13.4 percent nitrogen nitrocellulose systems are believed to represent values close to the maximum which may be obtained, it is probable that further increased performance will he obtained with the 13.6 percent nitrogen nitrocellulose and 50 percent RDX compositions, as coating and granulation studies continue. In addition, processing techniques for the preparation of 13.9 percent nitrogen nitrocellulose have been defined and a supply of single base, ball propellant of this nitrogen content is being prepared for deterrent coating and subsequent ballistic evaluation.

Processing techniques employed in solvent removal were found to exert a substantial effect upon the ballistic stability of these high energy types. Recognition of this has resulted in substantial improvement in stability over that exhibited by the high energy type originally developed for the Caliber .30 Lightweight Rifle Cartridge. Preliminary accelerated storage stability tests indicated that 20 percent nitroglycerin compositions, coated with ethyl centralite (and possibly diisobutyl phthalate), can be prepared which exhibit stability properties at 140 degrees F comparable to conventional energy ball propellants. At the 15 percent nitroglycerin level, stable propellants can be prepared with diisobutyl phthalate and ethyl centralite (and possibly dibutyl phthalate). Surveillance tests at 65.5 degrees C to determine chemical stability, indicate the high energy compositions easily exceed the minimum required surveillance life of 500 days.

As stated previously, the objective of this series of investigations was to provide for velocities greater than those presently obtained with conventional propellants. It is believed that future adequate aircraft gun performance will necessitate these increased projectile velocities.

20mm T130 Round (18,19)

In 1951, development of a ball propellant for the 20mm T130 cartridge, T118 gun (Navy 20mm Mark XII Gun) was undertaken under sponsorship of the Ordnance Corps working in cooperation with the Navy Bureau of Ordnance. A conventional energy rolled ball propellant, 0.034 in./0.025 in. granulation, was subsequently developed to meet the ballistic specifications for this round (3250 f/s at 78 feet at a maximum mean pressure of 58,000 psi). Functioning tests revealed the occurrence of a substantial amount of muzzle flash and breech flaming. Initial attempts to reduce flash by lowering the average flame temperature of the propellant (by incorporating coolants) yielded no significant results. However, through the use of a potassium nitrate salt coating, the secondary flash was eliminated, and the primary substantially reduced. Breech flaming was unaffected by the coating, and remained high with both ball and IMR propellant. (This flaming is thought to be essentially a problem of gun design.)

Although the results were not conclusive in regard to barrel life, early erosion tests with ball propellant (1951) revealed the occurrence of heavy coppering in the barrel. As a result, investigations were undertaken to develop methods of including antifouling agents, such as tin and basic lead carbonate, in the grain, so as to more fully exploit the barrel life potentialities of ball propellant.

Erosion tests were conducted during 1953 on 1000 round lots of three different ball propellant types to determine the effect of anti-fouling additives upon barrel life.(20) Following are the results.

Schedule	Prop	Anti Fouling Agent	Rnds Fired	Vel Drop	Vel Life	Rounds to Yaw Life
50-round bursts w/ 2-minute intervals, complete cooling each 600 rounds						
	Ball	Tin	1000	150		
	Ball	Tin Dioxide	1000	103		
	Ball	None	1000	62		

Since all three ammunition lots passed the test, no determination of the effect of antifouling agents upon barrel life could be made.

Larger samples of 4000 rounds each of ammunition, loaded with ball propellant containing coatings of tin dioxide and basic lead carbonate, were subsequently prepared, as well as a third lot containing no antifouling agent. In addition, 4000 rounds of T130 ammunition containing IMR propellant were obtained for test. Barrel erosion tests were conducted during 1955 with the following results.(21)

Schedule	Prop	Anti Fouling Agent	Rnds Fired	Vel. Drop	Vel Life	Rounds to Yaw Life
50-round bursts w/ 2-minute intervals, complete cooling each 600 rounds						
	Ball	Lead Carbonate	3000	59		
	Ball	Tin Dioxide	2850	130		2850
	Ball	None	2400	90		2400
	IMR		500 to 550	500 to 550		500 to 550

It is seen that the propellant coated with basic lead carbonate exhibited slightly better barrel life properties than did the other two ball propellant samples. The occurrence of numerous stoppages during test firing of both ball propellant samples containing anti-fouling additives caused the apparent barrel life of these lets to be somewhat high. Consequently, the results for the various ball propellant types should be interpreted more on a qualitative, rather than a quantitative, basis. However, the barrel life obtained with all three ball propellants was approximately five times greater than that obtained with IMR. The propellant containing the basic lead carbonate coating produced the least coppering, with moderately heavy coppering being noted with tin dioxide, and heavy coppering with the uncoated sample.

Extensive use of ball propellant for this cartridge has not been made to date.

Caliber .60 Round(22)

Almost simultaneously with the initiation of the 20mm Mark XII ball propellant development, work was begun on a ball propellant for the caliber .60 round, TI30 gun, with ballistic specifications calling for a velocity of 3550 f/s at 78 feet at a maximum mean pressure of 58,000 psi. Preliminary studies indicated the maximum granulation previously employed for small arms ball propellant, 0.034 in./0.025 in., yielded propellants too fast for the caliber .60 required ballistics. Consequently, development work was directed toward means of increasing the yield of the next larger cut, 0.04l in./0.034 in., so as to permit economical manufacture of this granulation which was suitable for caliber .60 propellant development. Hardening studies resulted in a slight increase in the maximum granulation obtainable with conventional processing techniques; however, the yields were too low to permit production of large scale quantities of caliber .60 propellant. As a result, studies were undertaken(13) on the development of a new method of grain formation, mechanical graining, which offered promise of permitting manufacture of larger grain diameters.

Barrel erosion tests on the propellant developed for this round (conventional energy, rolled, 0.04l in./0.034 in. granulation) demonstrated that ball propellant yielded substantially greater barrel life than did the extruded IMR propellant. (23,24) These results are presented in the following table. Coppering was noted in the barrels used in the tests where excessive yaw had occurred with ball propellant. To reduce this coppering, tin dioxide (an antifouling agent) was included in the propellant composition. Here again the wide superiority of ball propellant over IMR, in regard to barrel life, is evident.

Schedule	Barrel	Prop	Rnds. Fired	Vel. Drop	Rounds to Vel Life	Yaw Life
50-round bursts at 2-minute intervals, complete cooling each 600 rounds						
	Lined	Ball	650	60		
	Lined	Ball	3300	150		
	Lined	IMR	300	200+	300	
	Steel	Ball	650	88		650
	Steel	IMR	200	222	200	200

100-round bursts
each 15 seconds Steel
. . . . Steel . . . . Ball. . . . 300 27
. . . . Steel . . . . IMR. . . . 200 . . . .226. . . . . 200 200

The occurrence of breech and muzzle flash was noted in early samples of caliber .60 ban propellant. The latter was substantially reduced by the application of a surface coating of potassium nitrate. Breech flaming, obtained with both ban and extruded propellant, was not affected by this salt coating. As with the 20mm Mark XII gun, however, this was thought to be an inherent characteristic of the gun design.

The caliber .60 ball propellant developed was never extensively used due to the shelving of the caliber .60 T130 gun.

Mechanical Graining (13)

As stated previously, the granulation limitations of conventional hardening operations resulted in difficulties in obtaining suitable yields of the large granulation required for caliber .60 propellant. Consequently, investigations directed toward the development of a mechanical graining method and the installation of a pilot plant unit capable of the preparation of large granulation ball propellant by this method were initiated in 1952. This method involves the pumping of a nitrocellulose lacquer through an orifice plate into an aqueous medium, cutting of the resulting strings to a controlled size, followed by the usual hardening operations. Mechanical graining methods yielded larger grain diameters, together with narrower granulation spreads, than previously attained with conventional graining. Grains up to 0.050 inch were controllably produced with approximately 80 percent of the granulation being within a range of 10 percent of the average grain diameter.

The abandonment of the caliber .60 gun obviated the need for an extremely large granulation. However, the advantages to be gained by this method indicate it may well replace conventional graining, even in the preparation of ball propellants of smaller granulations. A program is presently underway to evaluate caliber .50 ball propellant made by the mechanical graining method.

20mm Hispano Suiza M99 Practice Round(25)

In 1951 development of a ball propellant to meet the ballistic requirements for the 20mm Hispano-Suiza M99 practice round was initiated. These requirements were subsequently modified to a velocity of 2680 f/s at 78 feet, at a maximum mean pressure of 46,000 psi. A conventional energy, rolled, 0.034 in./0.025 in. granulation ball propellant was developed which met these requirements.

Functioning tests of the first ball propellant developed revealed the occurrence of muzzle flash and breech flaming. Unlike the Mark XII and T130 guns, the latter is not an inherent characteristic of gun design. It was found that breech flaming was due to the M52A4 (zirconium) primer, since only a faint glow appeared at the breech during firing of either ball or IMR propellant with the M52A3 (styphnate) primer. Increasing the concentration of the salt coating decreased both muzzle flash and breech flaming. Subsequent functioning tests indicated muzzle flash to be about the same level for both IMR aid ball propellants.

As with the other large calibers, ball propellant yielded a substantial improvement in barrel life over that obtained with JMR propellant. The results of these erosion tests are as follows.(26)

Schedule	Barrel	Prop	Rnds. Fired	Vel Drop
40-round bursts each 30 seconds, complete cooling each 600 rounds				
	Chrome	Ball	5300	167
	Chrome	Ball	4640	160
	Chrome	IMR	2400	180
	Chrome	IMR	2400	171

Testing was terminated when engraving was no longer obtained on the rotating band cue to severe battering of the lards. The ball propellant (coated with tin dioxide) was evaluated in the M24A1 gun, and IMR the M3 gun. Since stoppages were encountered with the more complex M24A1, a direct comparison of the results obtained with the two propellants should not be made. (Taking the stoppages into account, Aberdeen Proving Ground estimated the true barrel life with ball propellant to be approximately 4000 rounds.) Very slight coppering was noted in the barrels fired with ball propellant. However, this small amount of coppering was thought to be more probably due to the effect of the chromium plating rather than the presence of the antifouling additive.

Large scale production of the ball propellant developed for this round has not been required to date.

20mm TI54/T199 Round(27)

In 1952, development of a ball propellant to meet the ballistic specifications of the 20mm T154 cartridge (velocity of 3250 f/s at 78 feet at a maximum mean pressure of 58,000 psi) was initiated. Conventional energy, rolled and unrolled, 0.034 in./0.025 in. granulation ball propellants were developed to meet these specifications.

Erosion tests on the rolled ball propellant (coated with tin dioxide) and the corresponding IMR propellant revealed the former yielded substantially longer barrel life, as shown by the following results.

Schedule	Barrel	Prop.	Vel Life	Yaw Life
100-round bursts At 15-seconds intevals, complete cooling each 375 rounds				
	Chrome	Ball	1150	167
	Chrome	IMR	300	180

Cook-off test(28) of combat rounds indicated that tall propellant permitted a longer burst without cook-off than did IMR.

Large scale evaluation tests are planned for this ball propellant type.

27mm Round(29)

Concurrent with the complete round development for the 27mm tail defense gun for bomber aircraft, work was initiated in 1951 on the development of a ball propellant to meet the required ballistics (muzzle velocity of 2000 f/s at a maximum mean pressure of 50,000 psi) for this gun.

A conventional energy, rolled, 0.034 in./0,025 in. granulation ball propellant was developed which met the specifications for the low velocity round using a 3500 grain projectile. Limited studies were conducted on the attainment of maximum velocity for the high velocity round (minimum muzzle velocity requirement of 2700 f/s, desired velocity 3000 f/s). Several conventional energy samples of 0.025 in./0.020 in. and 0.020 in./0.016 in. granulations, were developed which yielded muzzle velocities of approximately 2750 f/s with a 2700 grain projectile.

The decision of the Ordnance Corps to shelve the 27mm gun, in favor of 30mm gun development, obviated the need for further propellant, development for this round.

30mm Round(30)

Development of the 30mm tail defense gun was also accompanied by development of a ball propellant for the 30mm round, which was initiated in 1951.

Propellants were developed to meet the specifications for the m velocity T156 and the high velocity T204 round. These rounds have been replaced, however, by the T239 high velocity round which is in current usage. Ballistic specifications for this round call for a minimum muzzle velocity of 2750 f/s (with 3000 f/s desired) at a maximum mean pressure of 40,000 psi.

Development work on a ball propellant for the high velocity T239 is still in progress in order to attain the immediate goal of 2700 f/s and the ultimate 3000 f/s velocity goal. To date a rolled conventional energy ball propellant, 0.034 in./0.025 in. granulation, has been developed which yields approximately 2675 f/s. Since it is believed that the 2700 f/s velocity level represents close to the maximum which may be obtained with conventional energy propellants, emphasis is now being placed on both 13.2 and 13.4 percent nitrogen nitrocellulose compositions containing 15 percent nitroglycerin, in an effort to obtain velocities substantially above the 2750 f/s requirement, these new compositions will be deterred with diisobutyl phthalate rather than the dibutyl phthalate coating used in the conventional energy compositions, in light of the superior deterring qualities and ballistic stability obtained with the former in compositions containing more than 10 percent nitroglycerin.

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Development of the 30mm tail defense gun was also accompanied by development of a ball propellant for the 30mm round, which was initiated in 1951.

Propellants were developed to meet the specifications for the m velocity T156 and the high velocity T204 round. These rounds have been replaced, however, by the T239 high velocity round which is in current usage. Ballistic specifications for this round call for a minimum muzzle velocity of 2750 f/s (with 3000 f/s desired) at a maximum mean pressure of 40,000 psi.

Development work on a ball propellant for the high velocity T239 is still in progress in order to attain the immediate goal of 2700 f/s and the ultimate 3000 f/s velocity goal. To date a rolled conventional energy ball propellant, 0.034 in./0.025 in. granulation, has been developed which yields approximately 2675 f/s. Since it is believed that the 27OC f/s velocity level represents close to the maximum which may be obtained with conventional energy propellants, emphasis is now being placed on both 13.2 and 13.4 percent nitrogen nitrocellulose compositions containing 15 percent nitroglycerin, in an effort to obtain velocities substantially above the 2750 f/s requirement, these new compositions will be deterred with diisobutyl phthalate rather than the dibutyl phthalate coating used in the conventional energy compositions, in light of the superior deterring qualities and ballistic stability obtained with the former in compositions containing more than 10 percent nitroglycerin.

GENERAL

The conventional energy ball propellants developed for the different small arms rounds consist of 13.2 percent nitrogen nitrocellulose, impregnated with nitroglycerin ranging from concentrations of 8 to 10 percent. Excluding the caliber .60 and 27mm high velocity propellant, all the rolled propellants developed for caliber .50 or larger are based upon a 0.034 in./0.025 in. granulation. The required ballistics for the different rounds are attained by varying the concentration of the deterrent (dibutyl phthalate), the nature of the salt coating, and the degree of rolling. The webs for the 0.034 in./0.025 in. granulation range from approximately 0.018 to 0.024 inch, depending on the round for which the propellant is developed. Caliber .60 propellants (0.041 in./0.034 in. granulation) are rolled to approximately 0.026 inch.

Microscopic and spectrophotometric studies conducted at Frankford Arsenal (31) have demonstrated that impregnation of single base stock of the larger granulations (0.034 in./0.025 in. or greater) with nitroglycerin does not result in complete penetration of the grain. This yields a nonuniform distribution of nitroglycerin with the core of the grains being essentially unplasticized nitrocellulose, and surrounded by a nitroglycerin-rich outer layer. It has been found that the depth of penetration of nitroglycerin (and of the deterrent, dibutyl phthalate) follows normal diffusion behavior, being affected by the time and temperature of application and the concentration of the plasticizer. Since the depth of penetration is virtually independent of the grain diameter, the smaller granulations (caliber .30) are not characterized by this nonuniform distribution of nitroglycerin. While this heterogeneous distribution is not desirable (since it promotes burning digressively, it should be recognized that the performance of large caliber ball propellant has been obtained with propellants having this characteristic. It is probable that a homogeneous distribution of nitroglycerin in the matrix will further improve the ballistic performance. However, it is difficult to estimate the extent of improvement which may be obtained in this manner.

The selection of a suitable primer for ignition of ball propellant did not present any particular problem in caliber .50 ammunition. Satisfactory ignition was obtained with the various caliber .50 primers containing lead styphnate compositions. No ignition difficulties were encountered in the 20mm M99 round loaded with ball propellant when used with the M52A3 primer (nominal charge of 2.50 grains of lead styphnate mixture). However, in the larger 20mm T130 round, ignition time of tall propellant at low temperature increased significantly with the M52A3 primer. It was subsequently found that the M52A4 primer (nominal charge of 3.8 grains of zirconium mixture) yielded efficient ignition over the complete temperature range. The 20mm T154/T199 round, loaded with ball propellant, has been tested with both the M52A3 and M52A4 primers. While the latter yielded satisfactory ignition, marginal performance at low temperatures was obtained with the former. Satisfactory ignition of

30mm rounds containing approximately 1000 grains of ball propellant represents a demanding requirement. It has been found necessary both to use the M52A4 primer and to exercise care that the pellet weight is kept in the range of 4.0 to 4.5 grains of mixture.

Thermochemical interpretations of recent caliber .50 erosion tests (7) have shown that the greater barrel life obtained with ball propellant, relative to IMR, is attributable primarily to the lower average adiabatic flame temperature of the former.(32)

While it is realized that this report is by no means all encompassing, it is believed that the information presented herein offers a fairly concise picture of the development of ball propellant and its adoption in the field of military small arms propellants. The use of ball propellant offers several advantages, among them being high chemical stability and reduced cook-off characteristics relative to IMR. However, if one were asked to indicate the main advantage of this new propellant over existing service types, the answer might well be, "It has permitted substantial increases in barrel life of small arms." In the light of the development of these high cyclic rate-of-fire weapons, this advantage assumes considerable importance.

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29. Olin Mathieson Chemical Corp, Final Report, Contract DA-23-O72-ORD-227 (1955).
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31. Levy, M.E., "Microscopic Studies of Ball Propellant Report R-1286, Sep 1955.
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And, now we see why the military prefers ball propellant over all other propellant types - it provides longer barrel life, in general. This is because ball propellants have a lower flame temperature; WC846 has a deterred flame temperature about 100 degrees K lower than IMR 4895, and almost 400 degrees lower than 4350.

I know what you're going to ask, how can a propellant that is about 10% nitroglycerine have a flame temperature lower than those that are just plain nitrocellulose?

That answer is a bit complicated, so bear with me as we go through a little Propellant 101 first.

Gas is generated by the burning of the propellant. Since only the surface of the propellant grain is actually on fire, the amount of gas generated if governed by the total surface area of the grain at any point in time. If the propellant grain were a solid cylinder the surface area would decrease as time goes on as the burning reduces the diameter of the cylinder (we'll ignore the ends for now). If we put a single hole in the middle of the cylinder, we can get a constant surface area aflame, because the ID will grow as the OD shrinks. And, even better, if we put multiple holes in the cylinder, we can get the surface area to grow as the grain burns. If the surface area decreases with time, the propellant is digressive, if it stays the same, it is neutral, and if it increases with time, it is progressive.

The other major factor in propellant burning in the pressure at which the burning takes place. The higher the pressure, the faster the propellant burns. Ideally, the perfect propellant would burn at such a rate to maintain a constant pressure behind the bullet. But, in any case, a progressive burning propellant is required to achieve any sort of ballistic efficiency.

But, the single perforated cylinder grain is neutral, and a spherical (ball) grain is extremely digressive as the surface area decreases by the square of the radius. How can we hope to make these progressive? It is done by putting a "flame retardant" or deterrent, on the surface of the grain, the concentration of which decreases the further you move away from the surface. Ball propellants require a very high level of deterring to make the burn rate increase with time, even though the surface area is decreasing.

Since deterrents reduce the flame temperature, the high concentration of deterrents in ball propellants reduce the average flame temperature.

WC846
Undeterred flame temp – 3300 K
Deterred flame temp – 2225 K

IMR 4895
Undeterred flame temp – 3050 K
Deterred flame temp – 2325 K

IMR 4350
Undeterred flame temp – 3025 K
Deterred flame temp – 2600 K

And, one last thing – remember how we ignored the end burning of the cylindrical grain? Now, we can see why some propellants have longer grains than others. The ends of the grain burn towards the center, shortening the grain, how much this effects the overall surface area depends on the proportion of the length to diameter. For extremely long grains, like cordite, which are as long as the case itself, the end burning is almost negligible. And, on the opposite end, you have flake propellants like Unique or Bullseye, where the end burning is the primary gas generation surface meaning these grains are neutral burning as well.

For a more detailed look at interior ballistics watch this:
[ame="https://www.youtube.com/watch?v=CgXz-njLLV4"]Fundamentals of Ballistics - YouTube[/ame]