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AFATL-TR-76-155

IMPROVED 20MM PLASTIC ROTATING BANDS

DEBELL AND RICHARDSON, INC.
WATER STREET
ENFIELD, CONNECTICUT 06082

DECEMBER 1976

FINAL REPORT: JANUARY 1975-OCTOBER 1976

Distribution limited to U. S. Government agencies only; this report documents test and evaluation; distribution limitation applied December 1976. Other requests for this document must be referred to the Air Force Armament Laboratory (DLDD), Eglin Air Force Base, Florida 32542.

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This project included the study of processing parameters, material variations, and geometry factors for producing highly reliable nylon 12 plastic rotating bands bonded to M56A4 20mm projectiles. Included were the development of material and process specifications. Production tooling and equipment were developed, and a large volume of plastic banded projectiles was fabricated under simulated high volume conditions. The efficacy of each developed parameter was verified by gun fire testing.

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SUMMARY

The objective of this program was to develop a complete data package for the production of highly reliable plastic rotating bands for use on 20mm projectiles. The data package established the geometry of the rotating band and band seat, allowable dimensional tolerances, characterization and control of plastic material properties, fabrication techniques compatible with mass production, and methods of quality control.

The initial groundwork for the program was developed by DeBell & Richardson in 1974 under Air Force Contract F08635-73-C-0030, where rotating bands of nylon 12 plastic were molded and bonded directly to shallow band seats on M55 20mm projectiles. The bands were successfully tested under a variety of firing conditions, but material and fabrication data points were narrow in scope. Moreover, that activity used band seats of 0.50 inch in length, a value incompatible with existing M39 and M61 gun feed systems.

To be compatible with the current gun systems, the band length could be no longer than 0.280 inch, and the depth, in consideration of maximized payloads for the explosive projectiles, could be no deeper than 0.020 inch. Based on these parameters the band seat geometry was established early in the program, and a development effort was undertaken to broaden the spectrum of nylon rotating band materials and the adhesives for bonding. Included within the development effort were the establishment of suitable processes for preparing the projectiles for manufacture, the molding sequence, and the bonding process. The external geometry of the band was optimized for maximum wear resistance in conjunction with minimum fringing and other deleterious aerodynamic effects. Each step of the development was verified by gun fire tests performed by the sponsor prior to incorporation as a valid process parameter, and finally, material and process specifications were prepared.

The development work is reported herein, including the reports of screening and test firing on more than 2,000 samples. A lot of 39,600 was fabricated with nylon 12 rotating bands and shipped to the sponsor for final evaluation. Materials and process specifications governing this activity are included herein.

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PREFACE

This program was conducted by DeBell & Richardson, Division of Springborn Laboratories, Inc., Water Street, Enfield, Connecticut 06082, under Contract F08635-75-C-0070 with the Air Force Armament Laboratory, Armament Development and Test Center, Eglin Air Force Base, Florida 32542. In succession, Captain John Edgar, Lieutenant Larry Laurence, Lieutenant Jeff Rawles, and Lieutenant Bill Wade managed the program for the Armament Laboratory. The program was conducted during the period from January 1975 to November 1976.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER:

GERALD P. D'ARCY, Colonel, USAF
Chief, Guns, Rockets, and Explosives Division

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SECTION I

INTRODUCTION

During the early 1950's the Naval Weapons Laboratory developed and patented plastic rotating bands made from nylon 6/6 for use on 20mm and 30mm projectiles. The plastic band was mechanically locked to the projectile through the use of a knurled double dovetail band seat extending to a depth of 0.065 inch below the projectile bourrelet. The successful Navy tests of these projectiles showed that they would increase useful barrel life by at least a factor of three. After being stored for over twenty years, some of these same projectiles were test fired by the Air Force Armament Laboratory. These tests demonstrated that the Navy plastic rotating band will perform all the functions required of a rotating band without a single failure.

More recently, the Air Force Armament Laboratory demonstrated a plastic rotating band design which differed from the Navy design in the method of attachment to the projectile body. The recent design used a band seat consisting of a smooth rectangular cut extending 0.020 inch below the projectile bourrelet surface. The plastic rotating band, made from nylon 12, was adhesively bonded directly to the steel projectile body and eliminated the need for any mechanical attachment. The feasibility of this approach was demonstrated by DeBell & Richardson under Contract F08635-73-C-0030.

Resulting from that activity was a program in which the concept was adapted to a shorter band seat (0.280 inch versus the original 0.500 inch), the material spectrum was broadened, and reasonable processing was established. The details of the program are presented in this report, reflecting a plastic rotating band which can be manufactured inexpensively and with high volume techniques.

The availability of a highly reliable plastic rotating band of the above design is a major part of the effort to develop an improved 20mm high explosive projectile with increased lethality. The increased lethality requires both increased muzzle velocity and explosive payload. To meet these two requirements and stay within the chamber pressures allowable in the M61 gun means that the projectile wall thickness must be decreased. Thinner walls provide more internal volume for explosive and reduce the projectile mass since low density explosive is substituted for the steel removed. The lower mass, in turn, results in a higher muzzle velocity if gun chamber pressures are held constant. However, if the thinner projectile walls are to withstand the compressive stresses generated by axial acceleration, the depth of the rotating band seat must be minimized. This is made possible by the use of a bonded plastic rotating band.

SECTION II

TECHNICAL DISCUSSION

Technical effort in this program was directed toward establishing a band seat design, establishing a cleaning procedure for the band seat, selecting the plastic rotating band material, developing proper molding parameters, establishing bonding parameters, and developing external geometry factors consistent with projectile performance. The use of protective coatings was also investigated. Each of these areas is discussed below.

BAND SEAT DESIGN

The band seat design was established early in the program as a simple rectangular groove machined into the projectile body, with dimensions of 0.280 inch in length and 0.020 inch in depth. It was recognized early in the program that the seat length must be maximized in order to minimize band shear and bearing stresses. For the approximate 1,000 grain noseless and empty M56A4 projectile used in the program, having an estimated polar moment of inertia of 0.015 lb-in^2 and a 0.280-inch band seat length, the estimated stress levels were 44,000 psi in bearing on the driving edge faces of the rotating band, 2,700 psi in shear at the bond line between the rotating band and the band seat, and 3,400 psi in shear at the base of the engraved rotating band lug. Of these, the driving edge bearing stress is a measure of driving edge wear, and it was already demonstrated in previous development work (Contract F08635-73-C-0030) that wear resistance of the plastic rotating bands was low. Efforts to reduce the seat length to values less than 0.280 inch would certainly increase the driving edge wear.

However, trials were made using nylon 12 rotating bands molded and bonded to band seats of 0.200-inch length and 0.020-inch depth. This series, identified as EG-D68-B, were test fired at Eglin AFB in a standard M61 20mm Mann barrel with nine rifling lands. The results, presented in Table 1, showed that, although the bands remained intact, the driving edge surface was virtually worn away at -65°F and at ambient temperatures, and it was definitely worn smooth at 160°F. Figure 1 shows a typical result of firing trials.

TABLE 1. RESULTS OF FIRING TRIALS: EG-D68-B PROJECTILES, 0.200-INCH BAND LENGTH, M61 MANN BARREL

Test Temp.	Muzzle Velocity, Feet per Second			Remarks
	Range	Mean	Std. Dev.	
Ambient	3753 - 3827	3789	28	Intact and almost wiped
- 65°F	3402 - 3760	3636	151	Intact and almost wiped
160°F	3196 - 3803	3523	207	Intact but wiped smooth

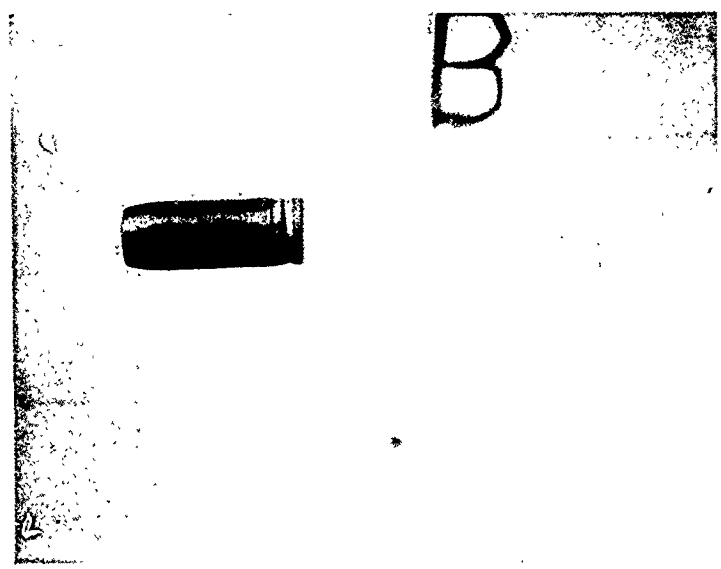


Figure 1. EG-D68-B Series Projectile with 0.200-Inch Band Length, In-Flight at 3,803 Feet per Second Muzzle Velocity and at 160°F, M61 Gun

When these same projectiles were subjected to firing trials using an experimental saw-tooth barrel made by Philco-Ford in an unrelated contract, the results, because of a reduction in driving edge bearing stress due to an increase in the number of rifling lands, were significantly improved. In this testing, noseless and empty projectiles (63-gram mass) as well as projectiles with noses (84-gram mass) were trialed, and the results are listed in Table 2. Figure 2 shows a typical result of firing trials.

TABLE 2. RESULTS OF FIRING TRIALS: EG-D68-B PROJECTILES, 0.200-INCH BAND LENGTH, SAW TOOTH BARREL

Test Temp.	Weight, grams	Muzzle Velocity, Ft/Sec			Remarks
		Range	Mean	Std. Dev.	
Ambient	84	3650 - 3675	3658	11	Intact and stable
Ambient	63	3812 - 3847	3826	16	Intact and stable
- 65°F	63	3508 - 3664	3599	67	Intact and stable
- 65°F	84	3418 - 3547	3475	47	Intact and stable
165°F	63	3987 - 4000	3992	5	Intact and stable
165°F	84	3749 - 3787	3773	16	Intact but mostly wiped; yawing

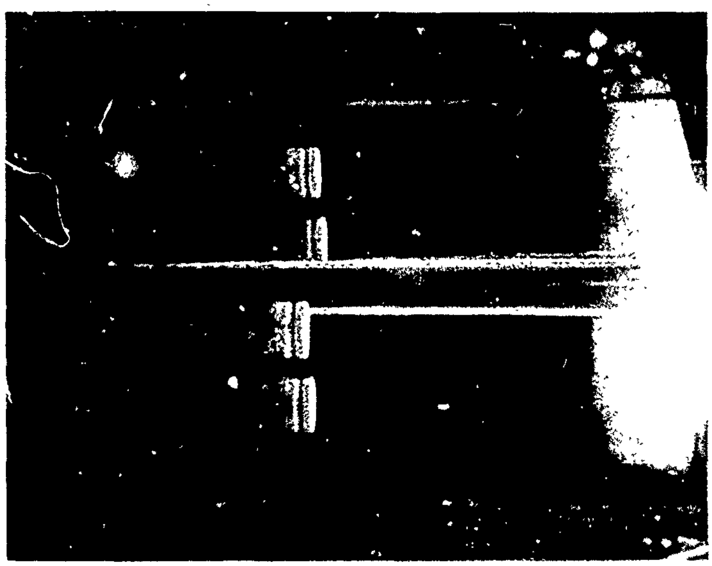


Figure 2. EG-D68-B Series Projectile with 0.200-Inch Band Length, In-Flight at 3,988 Feet per Second Muzzle Velocity and at 165°F, Saw-Tooth Barrel

Clearly, the results of these trials showed that a reduced band length would be satisfactory only if the barrel had a sufficient number of lands and grooves to result in bearing stress levels low enough to preclude excessive wear. Since such a barrel existed only on an experimental basis, it could not be used as criterion for establishment of a band seat length. The band seat length was thus established at the maximum allowable length of 0.280 inch.

A series of trials was made on projectiles having band seat depths less than the baseline value of 0.020 inch. Using depth increments of 0.015, 0.010, 0.005, and 0.000 (zero depth) inch, a band seat length of 0.280 inch, and nylon 12 for the rotating band, R&D Series 117621-74 was prepared and test fired at Indiana Ordnance, Connersville, Indiana, using a new M61 gain twist Mann barrel. The testing was performed as a part of a concurrent contract with Wright-Patterson AFB, Ohio, Contract F33615-75-C-5226, and the results are as presented in Table 3. Figures 3 through 6 illustrate the results of the firing trials at the various band depths.

Although the results show that a band depth of 0.015 inch was satisfactory for nylon 12 rotating bands, it was clearly on the marginal edge. The increase in fringing and severe slivering at band depths of 0.010 inch and below, including zero depth, precluded the use of these depths with nylon 12 on 20mm projectiles. The band depth was thus established at 0.020 inch.

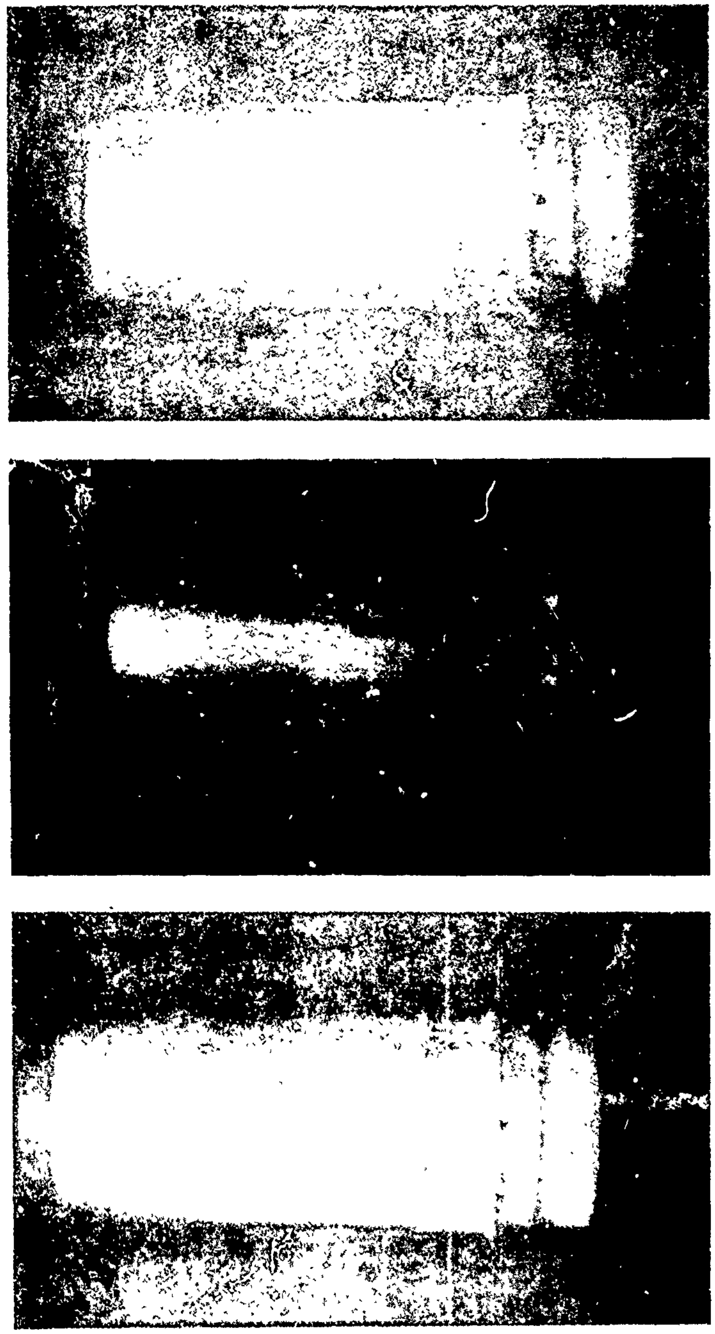
From these developments the band seat design was frozen at a 0.280-inch length and a 0.020-inch depth, and the concept was presented on contractor drawing EG-D1-B. As further developments in surface preparation progressed, the design was modified to include zinc phosphating in accordance with Federal Specification TT-C-490B, in a fine grain, minimum weight coating. The sponsor prepared Air Force drawing 747650 to reflect the band seat configuration and the phosphate coating, and this drawing was used as the procurement specification for government-furnished projectiles to be used by the contractor in production.

SURFACE PREPARATION

The preparation of the rotating band seat prior to coating with the adhesive/primer was considered to be a most important factor relative to maximizing the final bond strength, both before and after environmental conditioning. Various processes were studied, and they were as presented in Table 4. After preparation, projectiles were primed with M&T 253-P primer, baked, molded with nylon 12 rotating bands, and the bands were induction bonded. The finished projectiles were subjected to a battery of environmental tests, including 160°F temperature soak, -65°F temperature soak, salt spray exposure, thermal shock, and 28-day temperature and humidity cycling in

TABLE 3. RESULTS OF FIRING TRIALS: 117621-74 PROJECTILE SERIES, REDUCED BAND SEAT DEPTHS

Seat Depth, in.	Test Temp. °F	Muzzle Velocity, Ft/Sec		Remarks
		Range	Mean	
0.020	70	3884 - 3891	3888	Intact and satisfactory
0.020	-65	3764 - 3862	3797	Intact and satisfactory
0.020	160	3771 - 3805	3791	Intact and satisfactory
0.015	70	3877 - 3891	3884	Intact and satisfactory
0.015	-65	3841 - 3884	3862	Heavy rear fringing
0.015	160	3777 - 3841	3805	Rear fringe and long slivers
0.010	70	3802 - 3862	3832	Long feathers and chipping
0.010	-65	3757 - 3855	3814	Chunking and fringing
0.010	160	3784 - 3834	3815	Flaking, tearing, fringing and slivering
0.005	70	3877 - 3884	3881	Ripping, tearing, and flaking with furry slivering
0.005	-65	3805 - 3891	3846	Chunking, flaking, tearing, and furry slivering
0.005	160	3771 - 3812	3793	Long furry slivers, flaking, peeling, and partial discards
Zero	70	3841 - 3906	3865	Wear, flaking, peeling, and furry slivers
Zero	-65	3777 - 3848	3816	Flaking, peeling, ripping, and furry slivers
Zero	160	3743 - 3805	3776	Long furry slivers, peeling, and ripping



3,777 Feet per Second
at 160°F

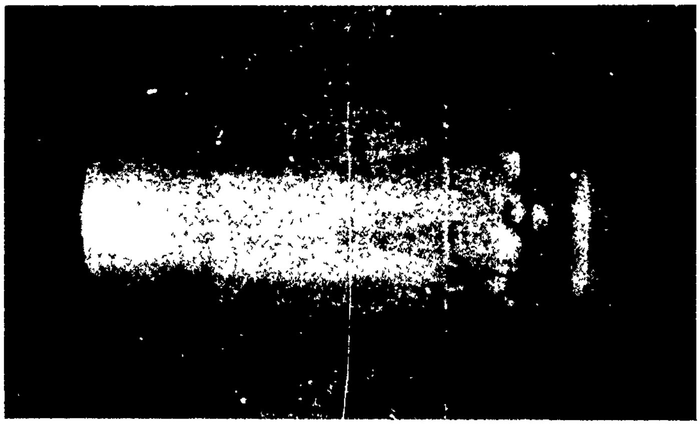
3,891 Feet per Second
at 70°F

3,855 Feet per Second
at -65°F

Figure 3. Reduced Band Seat Depth Study: 117621-74-15 Series Projectile with 0.015-Inch Band Seat Depth

3,819 Feet per Second
at 160°F

3,862 Feet per Second
at 70°F



3,855 Feet per Second
at -65°F

Figure 4. Reduced Band Seat Depth Study: 117621-74-10 Series Projectile with 0.010-Inch Band Seat Depth

3,795 Feet per Second
at 160°F

3,884 Feet per Second
at 70°F

3,891 Feet per Second
at -65°F

Figure 5. Reduced Band Seat Depth Study: 117621-74-5 Series Projectile with 0.005-Inch Band Seat Depth

3,795 Feet per Second
at 160°F

3,848 Feet per Second
at 70°F

3,798 Feet per Second
at -65°F

Figure 6. Reduced Band Seat Depth Study: 117621-74-N Series Projectile with No Band Seat

accordance with MIL-STD-810B, Method 507, Procedure IV. Projectiles which withstood these environmental exposures were subjected to firing tests by the sponsor using a GAU-9 30/20 Mann barrel at velocities in excess of 4,000 feet per second. The GAU-9 30/20 Mann barrel system consists of a standard M39 20mm constant twist Mann barrel section specially adapted with a 30mm breech. This combination was developed for use with M55 TP projectiles, as reported in AFATL-TR-74-106, where high propellant loadings were necessary for muzzle velocities up to 4,400 feet per second. The projectiles were press fit to an adapter, and the adapter was fitted to the 30mm cartridge case containing the high propellant load.

TABLE 4. BAND SEAT PREPARATION PRIOR TO PRIMING

Process No.	Seat Surface	Cleaning Process
115526	Bare steel	Wire brush abrasion, hot perchloroethylene vapor degrease, hot alkaline wash, water rinse, acetone rinse.
118205	Bare steel	Toluene wash
EG-D19-B	Bare steel	Hot perchloroethylene vapor degrease, toluene wash and wipe.
EG-D20-B	Bare steel	Hot alkaline wash, acetone rinse.
EG-D21-B	Zinc phosphated per TT-C-490 B Type I, fine grain	Acetone rinse
EG-D22-B	Cadmium plated	Toluene wash
EG-D23-B	Bare steel	Hot perchloroethylene vapor degrease
EG-D24-B	Bare steel	Warm sodium metasilicate immersion, distilled water rinse, acetone rinse
EG-D27-B	Nickle plated	Toluene wash

Referring to Table 4, Process numbers 115526 and 118205 were eliminated without any testing by virtue of their inability to remove machined-in smut. The other processes were subjected to the above-mentioned environmental exposures, and all withstood the high and low temperature soaks and the thermal shock test. However, the EG-D24-B process was demonstrated to have developed a bond weakness as witnessed from falling dart impact tests. (The falling dart impact test is described in report AFATL-TR-74-106.) Salt spray testing on this process induced corrosion under the rotating band, whereas the same testing produced no deleterious effects on the other tested processes. The temperature and humidity test produced corrosion on all processes having bare steel band seats and debonding on the cadmium-plated seats. There were no deleterious effects as a result of this cycling on either the zinc-phosphated or nickle-plated seats.

Samples from these environmental exposure groups were subjected to firing trials by the sponsor. Unfortunately, the trials were performed at high frequency (up to 158 rounds per day), and high barrel temperatures resulted. Rounds, regardless of their preconditioning (high and low temperature soaks) prior to firing, remained chambered sufficiently long within the hot barrel to absorb its heat, and all performed poorly as evidenced by wiped bands and instability.

However, the firing trials were sufficiently discriminatory to be able to permit a selection of the final substrate preparation. Projectiles with zinc-phosphated band seats showed no evidence of band discard, whereas the converse was true for the nickle-plated units. Substrate preparation was finalized as fine grain, minimum weight zinc phosphating in accordance with Federal Specification TT-C-490B, and this process was incorporated into Air Force drawing 747650. The cleaning process prior to priming is delineated in contractor process specification DRPS 6046.3.3, a copy of which is appended herein.

MATERIALS SELECTION

In previously successful development work performed by the contractor and disclosed in AFATL-TR-74-106, the plastic rotating band material for 20mm projectiles was isolated to be Huls L1801 nylon 12. The bands were induction bonded through an epoxy primer, M&T 253-P. Since this selection was limited it was necessary to study other rotating band material candidates and adhesives in order to broaden the manufacturing spectrum. The results of these studies are presented herein.

Rotating Band Materials. Huls L1801 nylon 12 was used as the baseline rotating band material. Type 12 nylons of other molecular weights and from other manufacturers were investigated, as well as were the effects of fillers incorporated within the polymer. Nylon 11, due to its similarity to nylon 12 and its partial success achieved in the previous effort reported in AFATL-TR-74-106, was also investigated. Each material was injection molded onto primed bare steel band seats, and the molded bands were induction bonded. Each type was subjected to firing trials by the sponsor.

Initial firing trials were performed using the hybrid GAU-9 30/20 constant twist Mann barrel. The results, presented in Table 5, were inconclusive, although the Huls L1901 and L2101 nylon 12 materials fared well. The bands tested in these trials were molded through the use of a ring gate. Testing was repeated using sub-gate molded rotating bands, all bonded by induction through M&T 253-P primer and a standard M61 gain twist Mann barrel. The results of this retest are as shown in Table 6, and they illustrate that the Huls L1801 nylon 12 did perform best as a 20mm projectile rotating band, but that Huls L1901 nylon 12 could be a satisfactory alternate. The L1901 material was, however, a more difficult material to process than the L1801. The results also show that a blend of two Rilsan nylon 11's, BMNO and BMNO P40, performed well with the exception of the presence of long slivers developed along the edges of the driving faces. Nylon 11, however, is slightly more costly than nylon 12, but more than likely could be used satisfactorily as a rotating band material. The presence of low levels of fiberglass reinforcement in nylon 12 proved to be deleterious to rotating band performance in the shallow band seat. The effect was to reduce the malleability of the material.

Contractor material specification DRMS 6046.3.2 was prepared to reflect the sponsor approved nylon 12 rotating band materials, and a copy is included herein. Figures 7 through 11 show the flight characteristics of each material candidate subjected to firing trials in the M61 Mann barrel.

Adhesive/Primers. The adhesive/primer developed under Contract F08635-73-C-0030 and reported in AFATL-74-TR-106 for use with nylon 12 rotating bands on 20mm projectiles was M&T 253-P epoxy system. This material continued to show excellent performance when used with nylons 11 and 12 in this program. However, other types of adhesives were also investigated. Three film-forming adhesives were obtained from Loctite Corporation, and they were identified as L4-4, L4-5, and L4-34. It was the supplier's belief that at least one of these materials could be used without the need of the secondary induction bonding process, but this was not proven in the development program. Only the L4-4 adhesive, in conjunction with induction heating, had any degree of success as a bonding medium for nylon 12 rotating bands, but the results were inconsistent. In addition, the premixed shelf life of the material was very limited in comparison with the M&T 253-P primer; the latter has a shelf life measured in years. The M&T 253-P system was adopted for use with nylon 12 rotating bands, and contractor material specification DRMS 6046.3.1 was prepared. A copy of that specification is included herein.

TABLE 5. FIRING TEST RESULTS:

ALTERNATE BANDING MATERIALS MOLDED BY RING GATING, GAU-9 30/20 MANN BARREL

Specimen Identification	Band Material	Primer	Test Temp.	Velocity, fps		Status
				Range	Avg.	
EG-D15-B-1	Huls L1901 nylon 12	M&T 253-P	ambient	3962 - 4105	4060	4 units; 2 feathering, others showing some wear.
			160°F	4026 - 4095	4055	10 units; 5 wiped, 1 feathering, all wearing heavily.
			-65°F	3861 - 4085	3995	10 units; 1 lift-off. Rejected.
EG-D15-B-2	Huls L2101 nylon 12	M&T 253-P	ambient	3978 - 4105	4064	4 units; all wearing.
			160°F	3997 - 4112	4081	10 units; 1 lift-off, 1 wipe off, all wearing heavily. Rejected.
			-65°F	3765 - 3994	3901	10 units; 1 lift-off, all wearing. Rejected.
EG-D15-B-3	Rilsan AMNO nylon 12	M&T 253-P	ambient	3978 - 4125	4036	4 units; 1 chip discard, 1 rear lift-off, all wearing heavily. Rejected.
			160°F	3915 - 4065	4029	10 units; all wiped, some lifting chips. Rejected.
			-65°F	3826 - 3965	3912	10 units; moderate wear, 1 unit discarded rear chip. Rejected.

TABLE 5. FIRING TEST RESULTS: ALTERNATE BANDING MATERIALS MOLDED BY RING GATING, GAU-9 30/20 MANN BARREL (CONCLUDED)

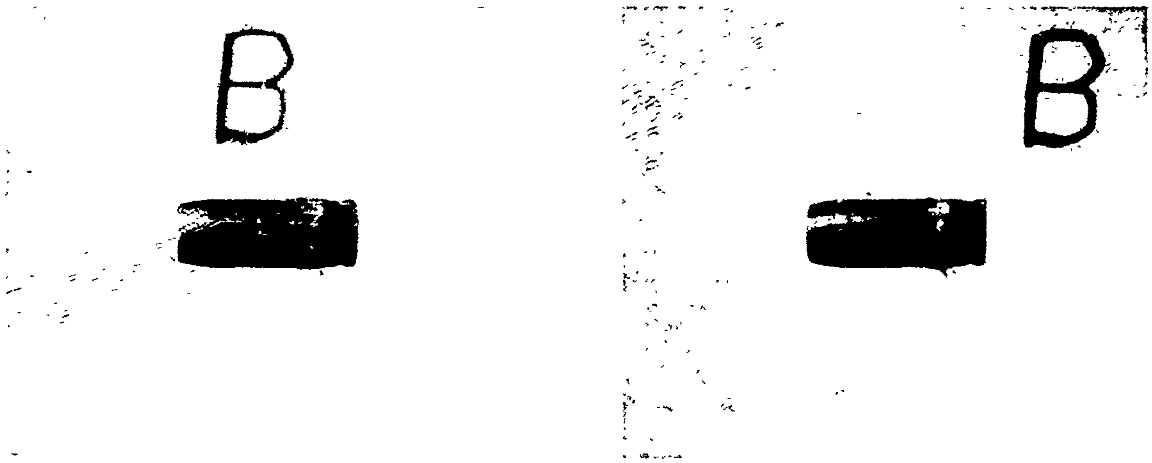
Specimen Identification	Band Material	Primer	Test Temp.	Velocity, fps		Status
				Range	Avg.	
EG-D15-B-4	Rilsan RDG - 34 nylon 12	M&T 253-P	No data	No data	No data	No test. Units failed to pass 60 ft-lb falling dart test. Rejected.
EG-D15-B-5	Daciel L1801 nylon 12	M&T 253-P	ambient	4042 - 4072	4058	4 units; 1 slight feather, all wearing heavily.
			160°F	3928 - 4102	4053	10 units; 1 lift-off, 1 feathering, 3 wipe offs, all wearing heavily.
			-65°F	3762 - 3975	3866	10 units; 1 chip, 1 dis card. Rejected.
EG-D15-B-6	Thermofil N9-1000 FG	M&T 253-P	ambient	3965 - 4068	4027	4 units; 2 poor photographs only, no comments on performance.
	(10% glass reinforced Huls L1801 nylon 12)		160°F	4026 - 4125	4064	10 units; all units okay with moderate wear.
			-65°F	3774 - 3922	3870	10 units; 2 units discarded chips. Rejected.
EG-D17-B	Huls L1801 nylon 12	Loctite L4-4	160°F	3956 - 4058	4006	5 units; rear edge chipping and flaking on one unit. Rejected.
			-65°F	3925 - 4078	4015	5 units; 1 slight feather on one unit.

TABLE 6. FIRING TEST RESULTS: ALTERNATE BANDING MATERIALS MOLDED BY SUB-GATING, M61 GAIN TWIST MANN BARREL, M&T 253-P PRIMED SEATS

Specimen Identification	Band Material	Test Temp.	Velocity, fps		Status
			Range	Avg.	
EG-D61-B-10G	Thermofil N9-1000 FG (10% GR Huls L1801 nylon 12)	ambient	3690 - 3742	3718	5 units; all fringing and flaking. Rejected.
		160°F	3670 - 3851	3743	10 units; all fringing, 1 possible lift-off, no noticeable wear. Rejected.
		-65°F	3591 - 3716	3665	10 units; severe rear fringing, 1 possible rear lift-off, no wear. Rejected.
EG-D61-B-11B	Rilsan; blend of 3 pbv BMNO to 1 pbv BMNO P40 nylon 11's	ambient	3703 - 3739	3719	5 units; long slivers from driving edges, otherwise satisfactory.
		160°F	3860 - 3929	3907	10 units; long slivers from driving edges, moderate wear.
		-65°F	3657 - 3775	3706	10 units; slight fore and aft fringing, otherwise okay.
EG-D61-B-18T	Huls L1801 nylon 12	ambient	3697 - 3785	3751	5 units; slight fringing and with short slivers from driving edges.
		160°F	3857 - 4025	3941	10 units; heavy to moderate wear, fringing, some long slivers.
		-65°F	3611 - 3785	3692	10 units; slight fringing.

TABLE 6. FIRING TEST RESULTS: ALTERNATE BANDING MATERIALS MOLDED BY SUB-GATING, M61 GAIN TWIST MANN BARREL, M&T 253-P PRIMED SEATS (CONCLUDED)

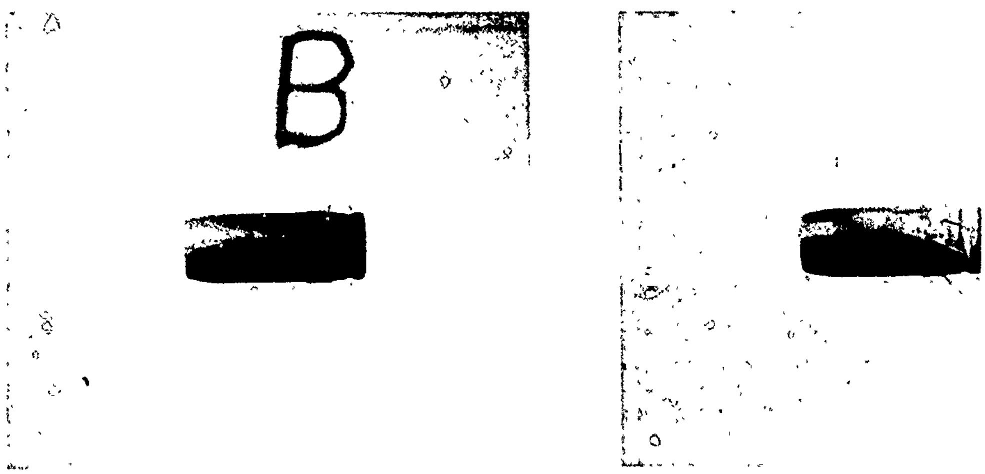
Specimen Identification	Band Material	Test Temp.	Velocity, fps		Status
			Range	Avg.	
EG-D61-B-19	Huls L1901 nylon 12	ambient	3657 - 3677	3667	2 units; fringing.
		160°F	3897 - 4051	3955	10 units; slivers, fringing, and heavy wear.
		-65°F	3802 - 3938	3879	10 units; slivers and fringing
EG-D61-B-21	Huls L2101 nylon 12	ambient	3674 - 3746	3718	5 units; long slivers.
		160°F	3750 - 4041	3925	10 units; very heavy wear (almost wiped), some slivering and fringing.
		-65°F	3857 - 3972	3917	10 units; fringing and slivering.



3,670 Feet per Second at -65°F

3,808 Feet per Second at 160°F

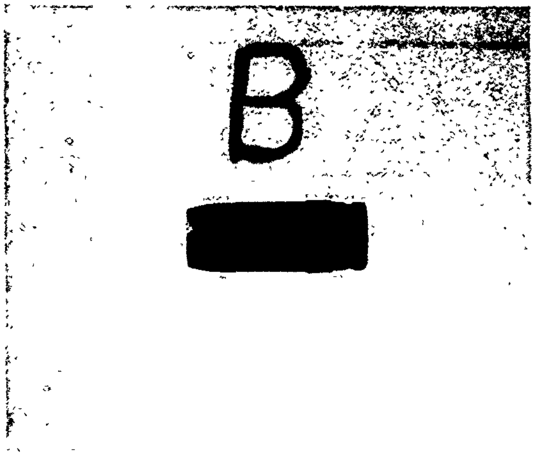
Figure 7. EG-D61-B-10G Series Projectile with 10 Percent Glass Reinforced Nylon 12 Rotating Band



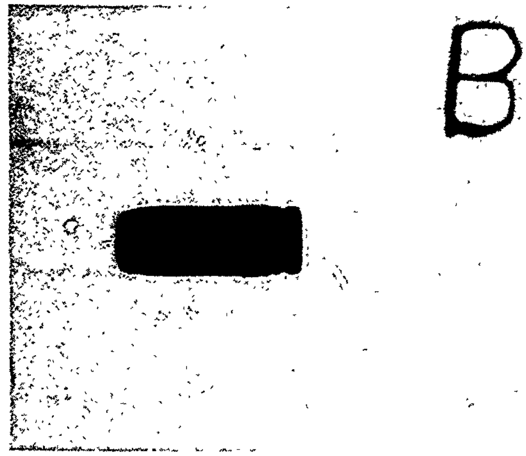
3,703 Feet Per Second at -65°F

3,920 Feet Per Second at 160°F

Figure 8. EG-D61-B-11B Series Projectile with Blended Nylon 11 Rotating Band

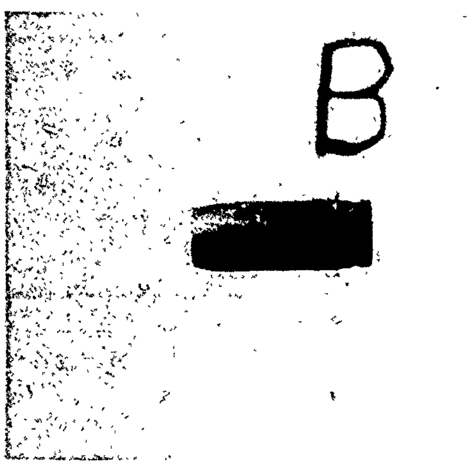


3,631 Feet Per Second
at -65°F



3,857 Feet Per Second
at 160°F

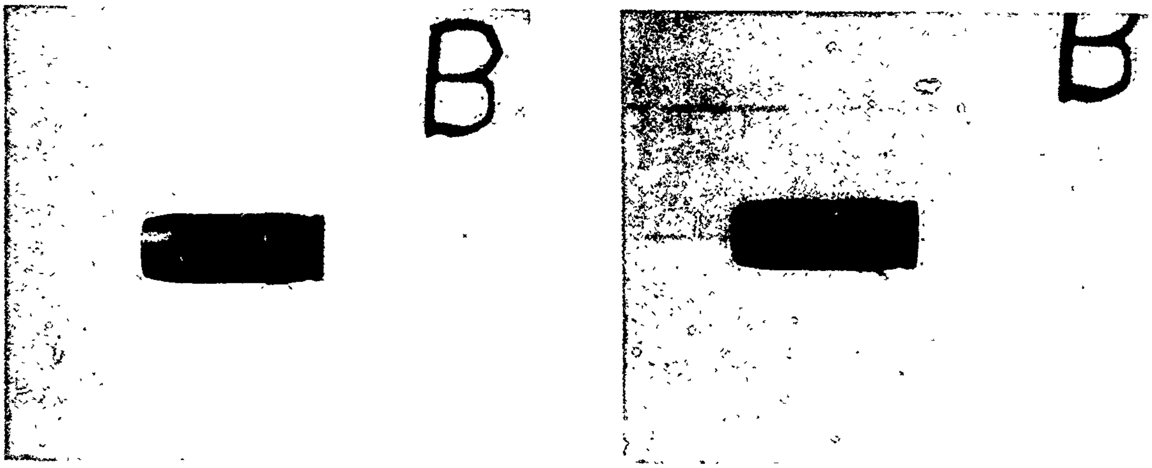
Figure 9. EG-D61-B-18T Series Projectile with Huls L1801 Nylon 12 Rotating Band



3,874 Feet per Second
at -65°F

4,011 Feet per Second
at 160°F

Figure 10. EG-D61-19 Series Projectile with Huls L1901 Nylon 12 Rotating Band



3,962 Feet per Second at -65°F

3,910 Feet per Second at 160°F

Figure 11. EG-D61-B-21 Series Projectile with Huls L2101 Nylon 12 Rotating Band

METHOD OF GATING

A foremost question to be resolved early in the program was the method of gating the injection molded nylon 12 rotating bands. Previous work by the contractor, as reported in AFATL-TR-74-106, utilized a ring gate to insure equal flow into the band and minimize the possibility of weld lines. However, ring gates require a post-molding secondary operation to remove them, whereas a submarine gate (sub-gate) would automatically be removed as the banded projectile is demolded, a recognized production plus factor. Sub-gates, however, would tend to produce weld lines on the band surface opposite from the gate entry, a condition potentially deleterious to band and projectile performance.

Early comparison trials between the gating methods favored ring gating over sub-gating, but these trials were performed using less than optimum processing. As the processing techniques improved during the course of the development, any differences between the two gating styles ceased to exist. As a consequence, the sub-gating style was adopted, and it was used for the priming, bonding, molding, and geometry studies development activities as well as with the final production. Firing trials with this gating showed no evidence of band failures attributable to it.

PRIMING VARIABLES STUDY

Once the primer had been established as M&T 253-P and the gating style (sub-gating) determined, a study was undertaken to evaluate various primer application and processing parameters in conjunction with banded projectiles. The primer was applicable either by brushing from full strength resin solution or by dipping (or spraying) from diluted solution. Diluents used were either methyl ethyl ketone or a special blend of solvents identified as M&T 200-T, and the dilution ratios were varied.

Starting with baseline conditions developed by the contractor as reported in AFATL-TR-74-106, a series of projectiles using various primer processing techniques were manufactured for test. The band seats were zinc phosphated, toluene washed, acetone rinsed, primed, and nylon 12 rotating bands were sub-gate molded and induction bonded to the projectiles. The priming variables studied included viscosity variations, the temperature of the projectiles prior to dip priming, the drying time (for solvents evaporation) prior to baking, and the baking schedule (time and temperature). Cleanliness of the primed band seats prior to molding was also evaluated. Brush application of the primer was not evaluated in the program, as this method is not readily adaptable to high volume processing techniques. Dip application was selected over spraying for its uniformity of coating and minimum material loss. Details of the processes studied are as listed in Table 7.

The priming variables projectiles were submitted to the sponsor for test, and the results of the firing trials are as presented in Table 8. They indicated that a wide range of variables could be tolerated in the priming process with perhaps cleanliness of the band seat prior to molding being the most critical factor. Contractor process specification DRPS 6046.3.3 was prepared to govern this process, and a copy is included herein.

TABLE 7. PRIMER VARIABLES, 115544 R&D SERIES

115544 Series Dash No.	Primer Viscosity, cps	Projectile Dip Temp., °F	Drying Time, min.	Bake Temp., °F	Bake Time min.
-C20	20	Ambient	15	450	20
-C25	20	Ambient	15	450	25
-C30	20	Ambient	15	450	30
-C35	20	Ambient	15	450	35
-C40*	20	Ambient	15	450	40
-C45	20	Ambient	15	450	45
-C50	20	Ambient	15	450	50
-C55	20	Ambient	15	450	55
-C60	20	Ambient	15	450	60
-D0	20	Ambient	0	450	40
-D24	20	Ambient	24 hr	450	40
-PH125	20	125	15	450	40
-PH175	20	175	15	450	40
-B350	20	Ambient	15	350	180
-B400	20	Ambient	15	400	90
-B500	20	Ambient	15	500	20
-REJ**	20	Ambient	15	450	40
-S0	(A)	Ambient	15	450	40
-S50	(B)	Ambient	15	450	40
-S33	(C)	Ambient	15	450	40
-S25	(D)	Ambient	15	450	40

*Standard priming sequence
**Primed projectile handled in band seat area after baking and before molding.
(A)Undiluted primer
(B)Primer diluted with 1 pbv of thinner
(C)Primer diluted with 2 pbv of thinner
(D)Primer diluted with 3 pbv of thinner

TABLE 8. RESULTS OF FIRING TRIALS: 115544 R&D SERIES, PRIMER VARIABLES - AMBIENT CONDITIONS

115544 Series Dash No.	No. of Units	Eglin AFB Shot Nos.	Muzzle Velocity, fps				Status
			Low	Avg.	High	*	
-C20	9	2026 - 2035	3806	3878	3937	42	Intact
-C25	9	2036 - 2044	3822	3861	3888	27	Intact
-C30	8	2045 - 2052	3832	3874	3937	37	Intact
-C35	9	2053 - 2061	3842	3877	3954	40	Intact
-C40	9	2062 - 2070	3805	3860	3986	63	Intact
-C45	9	2071 - 2079	3829	3905	3960	43	Intact
-C50	9	2080 - 2088	3881	3932	3976	32	Intact
-C55	9	2089 - 2097	3878	3947	3993	37	Intact
-C60	9	2098 - 2106	3819	3884	3924	34	Intact
-D0	9	2107 - 2115	3796	3909	3986	56	Intact
-D24	9	2116 - 2124	3852	3910	3957	35	Intact
-PH125	9	2125 - 2133	3796	3892	3980	65	Intact
-PH175	9	2239 - 2247	3747	3768	3789	15	Intact
-B350	9	2248 - 2256	3724	3780	3855	51	Intact
-B400	9	2257 - 2265	3724	3775	3819	29	Intact
-B500	9	2266 - 2274	3724	3761	3796	28	Intact
-REJ	9	2438 - 2441	3770	3792	3822	18	One unit chipped
-S0	9	2442 - 2449	3737	3786	3822	32	Intact
-S50	9	2451 - 2459	3708	3751	3835	37	Intact
-S33	10	2469 - 2478	3730	3772	3848	33	Intact
-S25	9	2460 - 2468	3744	3772	3819	23	Intact

*Standard Deviation

BONDING VARIABLES STUDY

The bond of the plastic rotating band through the adhesive/primer to the zinc-phosphated steel band seat is accomplished by induction heating. This technique was developed by the contractor, and it was reported in AFATL-TR-74-106. However, the range of potential variables was vast, and it included the configuration of the induction heating coil, time after molding of the rotating bands at which bonding was consummated, the effect of quenching after heating, the quench media, the radio frequency generator power requirements, and the surface temperature. Each of these variables was studied, and the listing of variables is as shown in Table 9.

In this series, the projectiles were zinc phosphated, toluene washed, and acetone rinsed. M&T 253-P primer was diluted to 20 centipoise viscosity with M&T 200-T thinner and applied to the projectiles by dip coating. After 15 minutes of air drying, the primer was baked at 450^{o}F for 30 minutes in a circulating hot air oven. The bands were molded at baseline conditions (see Table 13) and induction bonded at the conditions delineated in Table 9, followed by quenching (where applicable) in an aqueous antifreeze solution. Antifreeze was used for corrosion inhibition, but water, followed by hot air drying, was later adopted and used in final developments and production.

The study group of projectiles was submitted to the sponsor for test, and the results of firing trials on these specimen are presented in Table 10. The significant result was that bands that were induction bonded after four days from molding were degraded by absorbed moisture from the environment, and that drying these units prior to bonding in order to liberate the absorbed moisture was ineffectual. The best results were obtained using a loosely coupled coil of the dimensions shown on contractor drawing EG-D90-B and identified as coil number 115539-C1. Process specification DRPS 6046.3.5 was prepared to reflect the bonding process, and a copy is included herein.

TABLE 9. BONDING VARIABLES: 115545 R&D SERIES

Dash No.	Coil No.	Time After Molding	Open Coil Current, ma	Approx. Bond Temp. °F	Bond Time, sec	Time Before Quench, sec	Remarks
-TM5M	115539-C1	5 min	80	475	6 1/2	1	Baseline set-up
-TM30M	115539-C1	30 min	80	475	6 1/2	1	Baseline set-up
-TM1H	115539-C1	1 hr	80	475	6 1/2	1	Baseline set-up
-TM4H	115539-C1	4 hr	80	475	6 1/2	1	Baseline set-up
-TM1D	115539-C1	1 day	80	475	6 1/2	1	Baseline set-up
-TM2D	115539-C1	2 days	80	475	6 1/2	1	Baseline set-up
-TM4D	115539-C1	4 days	80	475	6 1/2	1	Baseline set-up
-TQ5	115539-C1	1 day	80	475	6 1/2	5	
-TQ15	115539-C1	1 day	80	475	6 1/2	15	
-TQN	115539-C1	1 day	80	475	6 1/2	no quench	
-B350	115539-C1	1 day	80	350	4 1/4	1	
-B400	115539-C1	1 day	80	400	5 3/4	1	
-B450	115539-C1	1 day	80	450	6 1/4	1	
-B500	115539-C1	1 day	80	500	7	1	
-PM	115539-C1	1 day	80	475	6 1/2	1	Tapers pre-machined
-FP	115539-C1	1 day	150	475	2 1/4	1	
-FPNQ	115539-C1	1 day	150	475	2 1/4	no quench	
-2FP	115539-C2	2 days	150	475	2 1/2	1	
-3FP	115539-C3	2 days	130	475	2	1	
-3/75	115539-C3	2 days	75	475	4	1	
-3/75R	115539-C3	2 days	75	475	4	1	Rotated in coil
-DRY	115539-C1	2 weeks	80	475	6 1/2	1	Dried 24 hrs at 175°F before bonding

TABLE 10. RESULTS OF FIRING TRIALS: 115545 R&D SERIES, BONDING VARIABLES

115545 Series Dash No.	No. of Units	Eglin AFB Shot Nos.	Muzzle Velocity, fps			Test Temp. °F	Status
			Low	Avg.	High		
-TM5M	4	2150-2153	3829	3847	3872	-65	Intact
-TM5M	5	2323-2327	3698	3712	3727	160	Intact
-TM30M	4	2154-2157	3783	3827	3862	-65	Intact
-TM30M	5	2328-2332	3727	3738	3753	160	Intact
-TM1H	4	2158-2161	3812	3841	3865	-65	Intact
-TM1H	5	2333-2337	3720	3757	3813	160	Intact
-TM4H	4	2162-2165	3770	3813	3849	-65	Intact
-TM4H	5	2338-2342	3724	3740	3763	160	Intact
-TM1D	4	2166-2169	3744	3763	3783	-65	Intact
-TM1D	5	2343-2347	3724	3756	3790	160	Intact
-TM2D	4	2170-2173	3721	3745	3780	-65	Intact
-TM2D	5	2348-2352	3734	3788	3832	160	Intact
-TM4D	9	2488-2496	3757	3795	3835	70	Intact
-TQ5	4	2174-2177	3766	3827	3872	-65	Intact
-TQ5	5	2353-2357	3740	3790	3829	160	Intact
-TQ15	4	2178-2181	3757	3800	3849	-65	Intact
-TQ15	5	2358-2362	3714	3770	3832	160	Intact
-TQN	4	2182-2185	3773	3801	3812	-65	Intact
-TQN	5	2363-2367	3727	3735	3744	160	Intact
-B350	4	2186-2189	3822	3830	3842	-65	Intact
-B350	5	2368-2372	3708	3729	3757	160	Intact
-B400	4	2190-2193	3819	3835	3845	-65	Intact
-B400	5	2373-2377	3770	3794	3839	160	Intact
-B450	4	2194-2197	3822	3836	3852	-65	Intact
-B450	5	2378-2382	3760	3798	3842	160	Intact
-B500	4	2198-2201	3770	3806	3829	-65	Intact
-B500	5	2383-2387	3757	3787	3822	160	Intact
-PM	4	2202-2205	3737	3812	3858	-65	Intact
-PM	5	2388-2392	3773	3788	3816	160	Intact
-FP	4	2206-2209	3799	3842	3862	-65	Intact
-FP	5	2393-2397	3721	3773	3835	160	Intact

TABLE 10. RESULTS OF FIRING TRIALS: 115545 R&D SERIES, BONDING VARIABLES (CONCLUDED)

115545 Series Dash No.	No. of Units	Eglin AFB Shot Nos.	Muzzle Velocity, fps			Test Temp. ^{o}F	Status
			Low	Avg.	High		
-FPNQ	4	2210-2213	3812	3826	3842	-65	Intact
-FPNQ	5	2398-2402	3747	3789	3826	160	Intact
-2FP	4	2214-2217	3780	3832	3872	-65	Intact
-2FP	5	2403-2407	3773	3809	3858	160	Intact
-3FP	4	2218-2221	3750	3776	3796	-65	Intact
-3FP	5	2408-2412	3688	3739	3770	160	Intact
-3/75	4	2222-2225	3753	3785	3799	-65	Intact
-3/75	5	2413-2417	3763	3789	3809	160	Intact
-3/75R	4	2226-2229	3747	3759	3776	-65	Intact
-3/75R	5	2418-2422	3753	3790	3839	160	One unit lifting off
-DRY	9	2479-2487	3737	3794	3829	70	One unit chipped

GEOMETRY STUDIES

The geometry of the band is dictated by its length, depth, the barrel configuration, and interior ballistic parameters. The band must obturate the hot gun gas as well as impart full spin to the projectile without discard. Fringing, slivering, petalling, chipping, chunking, etc., are considered undesirable, as they contribute to the drag and the accuracy of the projectile in flight.

The basic geometry of the plastic rotating band was dictated by the contract, where the band length was not to exceed 0.280 inch and the band depth below the projectile bourrelet was not to exceed 0.020 inch. To be consistent with the gun feed systems the external band diameter was not to exceed 0.828 inch, and fore and aft tapers would be necessary to combat the problems of fringing, petalling, etc. As a result of the projectile band seat design study previously described herein, the overall band length was established at 0.280 inch.

The standard 20mm M56A4 projectile used a copper rotating band having a diameter of 0.826 inch, a forward taper of 45 degrees, no aft taper (flat edge), and a length of 0.198 inch. The 20mm M55 TP projectile plastic rotating band developed by the contractor as reported in AFATL-TR-74-106 had a band diameter of 0.826 inch, a forward angle of 15 degrees, an aft taper of 6 degrees, and a band length of 0.500 inch. Direct application of the latter's dimensional profile would result in a band diameter of 0.826 inch, but the tapers would virtually intersect at the outer diameter. The result would be a small driving face bearing area which, during spin-up, would have most probably resulted in the same kind of smear type of failures encountered with the plastic banded M55 TP projectiles at Mach 4 muzzle velocities.

With this failure mode in consideration, initial projectile band geometry was established at 30-degree tapers fore and aft, and a band diameter of 0.826 inch. These projectiles performed with only moderate wear at velocities up to 4,000 feet per second, but fringing, both fore and aft, was quite evident. To combat the fringing problem the band tapers were reduced to 15 degrees fore and aft, with a subsequent reduction in effective band length. Projectiles with bands of this geometry exhibited less fringing, but a noticeable increase in driving edge wear ensued at velocities near the 4,000 feet per second mark.

It was further considered that the fringing, slivering, feathering, etc. could be further reduced by the incorporation of a proper combination of band diameters and tapers. A series of projectiles were manufactured with nylon 12 rotating bands in which the fore and aft tapers were varied from 7 degrees to 30 degrees, and the band diameters were varied from 0.826 inch to 0.813 inch. The 0.813-inch diameter was calculated to be the minimum value for a band which, through malleable displacement during the engraving sequence, would fill the volume of the barrel bounded by the rifling major diameter, rifling minor diameter, the lands, and the projectile bourrelet without significantly compressing band material into the band seat.

Firing trials on these rotating band geometry combinations were performed by the sponsor, and the results are presented in Table 11 and 12, for projectile series EG-D66-B and EG-D69-B, respectively. In the former series, both the fore and aft tapers were varied. Based on the results of this series, the second series was configured with a constant 15-degree forward taper. The results show that as the rear taper decreased, fringing decreased as well. However, driving edge wear increased. Conversely, as the rear taper increased, wear decreased, but fringing increased. Moreover, as the diameter decreased, wear increased and was compounded by the effects of the tapers. Microflash photographs of the extremes of the geometry conditions are as shown in Figures 12, 13, 14, and 15.

In a concurrent program with Wright-Patterson Air Force Base, Contract F33615-75-C-5225, the contractor had been developing geometries for other potential banding materials. As a result of that program, it was determined that any plastic band diameter in excess of the rifling major diameter was simply shaved off and flaked away during firing. This excess was often seen as fringing in microflash photographs. It was also determined that a forward taper of 22 degrees reduced the driving edge wear of plastic bands by an order of magnitude. In addition, for malleable plastic materials in projectiles with band seats of 0.020-inch depth, a trailing edge angle of 13 degrees was sufficient to minimize any other tendency towards fringing. These latter parameters were adopted for the nylon 12 plastic rotating bands, and the band configuration is as shown on contractor drawing EG-D74-B2.

TABLE 11. FIRING TEST RESULTS: EG-D66-B SERIES, NYLON 12 BANDS (PRELIMINARY GEOMETRY STUDIES)

No. of Units	Band Da. Inch	Fwd	Aft	Test Temp.	Eglin AFB Shot Nos.	Muzzle Velocity, fps		Status
						Range	Avg.	
2	0.824	15°	15°	ambient	2010 - 2011	3757 - 3776	3767	Fringing, no significant wear
3	0.824	15°	15°	160°F	2275 - 2277	3731 - 3747	3737	Fringing, moderate wear
2	0.824	15°	7°	ambient	2012 - 2013	3758 - 3793	3776	No fringing, very heavy wear
3	0.824	15°	7°	160°F	2278 - 2280	3688 - 3809	3763	Extreme wear, virtually wiped
2	0.820	15°	15°	ambient	2014 - 2015	3701 - 3753	3727	Slight fringing, no significant wear
3	0.820	15°	15°	160°F	2281 - 2283	3704 - 3826	3779	Slight fringing, moderate wear
2	0.820	15°	7°	ambient	2016 - 2017	3760 - 3858	3809	Extreme wear, almost wiped
3	0.820	15°	7°	160°F	2284 - 2286	3688 - 3842	3756	Wiped but stable
2	0.817	30°	30°	ambient	2018 - 2019	3767 - 3790	3789	Slivering, moderate wear
3	0.817	30°	30°	160 F	2287 - 2289	3662 - 3806	3750	Moderate wear, surface tearing
2	0.817	15°	7°	ambient	2020 - 2021	3858 - 3878	3868	Extreme wear, no fringing
3	0.817	15°	7°	160°F	2290 - 2292	3685 - 3773	3715	Wiped but stable
2	0.813	30°	30°	ambient	2022 - 2023	3675 - 3793	3734	Moderate wear, no fringing
3	0.813	30°	30°	160°F	2293 - 2295	3704 - 3822	3762	Extreme wear, virtually wiped
2	0.813	15°	7°	ambient	2024 - 2025	3826 - 3924	3875	Wiped and yawing slightly
3	0.813	15°	7°	160°F	2296 - 2298	3606 - 3806	3713	Wiped and yawing slightly

TABLE 12. FIRING TEST RESULTS: EG-D69-B SERIES (GEOMETRY STUDIES)

No. of Units	Band Dia. Inch	Aft. Angle	Test Temp.	Eglin AFB Shot Nos.	Muzzle velocity, fps Range	Avg.	*	Status
5	0.826	15°	ambient	2500 - 2504	3773 - 3809	3791	13	heavy wear, slight feathering
10	0.826	15°	160°F	2590 - 2599	3713 - 3854	3808	38	heavy wear, slight feathering
10	0.826	15°	-65°F	2740 - 2749	3855 - 3927	3883	25	very slight feathering
5	0.826	13°	ambient	2505 - 2509	3770 - 3835	3803	26	heavy, slight feathering
10	0.826	13°	160°F	2600 - 2609	3766 - 3871	3807	33	heavy wear, no feathering
10	0.826	13°	-65°F	2750 - 2759	3852 - 3934	3891	28	some wear, 1 of 10 feathering
5	0.826	11°	ambient	2510 - 2514	3743 - 3819	3771	30	heavy, wear, almost wiped; stable
10	0.826	11°	160°F	2610 - 2519	3782 - 3864	3817	24	very heavy wear, 4 of 10 wiped but stable
9	0.826	11°	30°F	2760 - 2768	3806 - 3891	3850	30	slight wear; slight fringe and feathers
5	0.826	9°	ambient	2515 - 2519	3770 - 3966	3854	100	wiped and yawing slightly
10	0.826	9°	160°F	2620 - 2629	3766 - 3877	3823	39	wiped and yawing slightly
10	0.826	9°	-65°F	2770 - 2779	3819 - 3911	3878	27	heavy wear, 1 of 10 wiped
5	0.826	7°	ambient	2520 - 2524	3770 - 3822	3791	20	wiped and yawing slightly
10	0.826	7°	160°F	2630 - 2639	3785 - 3841	3815	19	wiped and yawing slightly
10	0.826	7°	-65°F	2780 - 2789	3819 - 3891	3845	20	wiped and yawing slightly

TABLE 12. FIRING TEST RESULTS: EG-D69-B SERIES (GEOMETRY STUDIES) (CONTINUED)

No. of Units	Band Dia. Inch	Aft. Angle	Test Temp.	Eglin AFB Shot Nos.	Muzzle Velocity, fps Range	Avg.	*	Status
5	0.820	15°	ambient	2525 - 2529	3724 - 3770	3748	18	very heavy wear; 1 of 5 wiped
10	0.820	15°	160°F	2640 - 2649	3841 - 3926	3876	26	very heavy wear, all almost wiped
10	0.820	15°	-65°F	2790 - 2799	3793 - 3868	3843	25	heavy wear; long slivers
5	0.820	13°	ambient	2535 - 2539	3773 - 3898	3825	57	very heavy wear; 2 of 5 almost wiped
10	0.820	13°	160°F	2650 - 2659	3812 - 3890	3843	26	very heavy wear; 4 of 10 wiped
10	0.820	13°	-65°F	2800 - 2809	3806 - 3904	3866	32	heavy wear; feathering
5	0.820	11°	ambient	2540 - 2544	3747 - 3881	3812	56	very heavy wear; 2 of 5 wiped
10	0.820	11°	160 F	2660 - 2669	3779 - 3875	3831	33	very heavy wear; all almost wiped
10	0.820	11°	-65°F	2810 - 2819	3796 - 3891	3844	33	heavy wear, slight feathering
5	0.820	9°	ambient	2555 - 2559	3835 - 3891	3853	22	very heavy wear; 1 of 5 wiped
10	0.820	9°	160 F	2670 - 2679	3786 - 3825	3811	11	8 of 10 wiped; yawing slightly
10	0.820	9°	-65°F	2820 - 2829	3832 - 3917	3870	28	very heavy wear; 1 of 10 wiped
5	0.820	7°	ambient	2560 - 2564	3747 - 3838	3810	39	wiped and yawing slightly
10	0.820	7°	160°F	2680 - 2689	3743 - 3852	3791	40	wiped and yawing slightly
10	0.820	7°	-65°F	2830 - 2839	3786 - 3855	3821	27	wiped and yawing slightly
5	0.813	15°	ambient	2565 - 2569	3707 - 3796	3741	37	wiped and yawing slightly
10	0.813	15°	160°F	2690 - 2699	3738 - 3875	3809	48	very heavy wear, almost wiped
10	0.813	15°	-65°F	3840 - 2849	3779 - 3858	3825	28	heavy wear and feathering; 1 lift-off

TABLE 12. FIRING TEST RESULTS: EG-D69-B SERIES (GEOMETRY STUDIES) (CONCLUDED)

No. of Units	Band Dia. Inch	Angle	Test Temp.	Eglin AFB Shot Nos.	Muzzle Velocity, fps Range	Avg.	*	Status
5	0.813	13°	ambient	2570 - 2574	3688 - 3799	3724	46	4 of 5 wiped; yawing slightly
10	0.813	13°	160°F	2700 - 2709	3766 - 3845	3815	27	very heavy wear and wiping
10	0.813	13°	-65°F	3850 - 2859	3750 - 3842	3793	34	heavy wear; slight feathering
5	0.813	11°	ambient	2575 - 2579	3703 - 3858	3770	60	wiped and yawing slightly
10	0.813	11°	160°F	2710 - 2719	3793 - 3845	3820	17	5 wiped, 5 heavily worn
10	0.813	11°	-65°F	2860 - 2869	3701 - 3824	3761	40	heavy wear and feathering
5	0.813	9°	ambient	2580 - 2584	3756 - 3838	3793	40	wiped and yawing slightly
10	0.813	9°	160°F	2720 - 2729	3717 - 3858	3814	38	2 wiped, 8 heavily worn, yawing
10	0.813	9°	-65°F	2870 - 2879	3763 - 3855	3808	32	very heavy wear, 2 of 10 wiped
5	0.813	7°	ambient	2585 - 2589	3746 - 3828	3806	34	wiped and yawing slightly
10	0.813	7°	160°F	2730 - 2739	3783 - 3358	3819	24	wiped and yawing slightly
10	0.813	7°	-65°F	2880 - 2889	3766 - 3868	3827	30	wiped and yawing slightly

*Standard Deviation

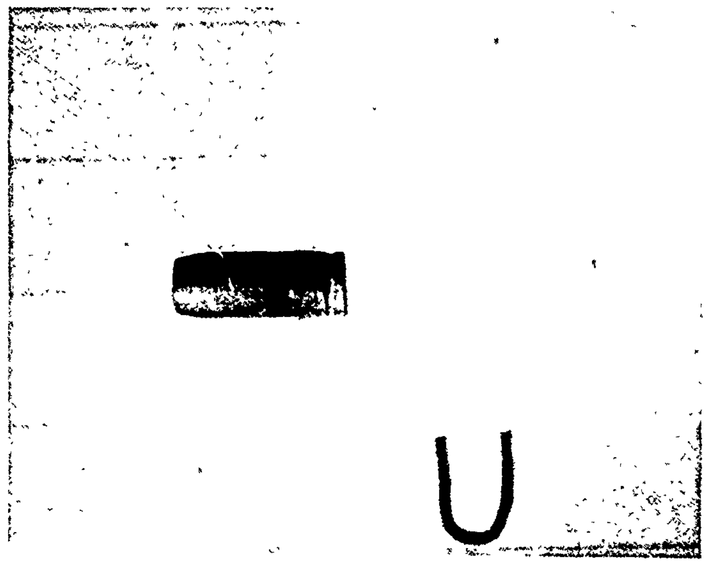


Figure 12. EG-D69-B-826/13 Series Projectile with 0.826-Inch Band Diameter, 15-Degree Forward Taper, and 13-Degree Aft Taper, In-Flight at 3,786 Feet per Second Muzzle Velocity at Ambient Conditions

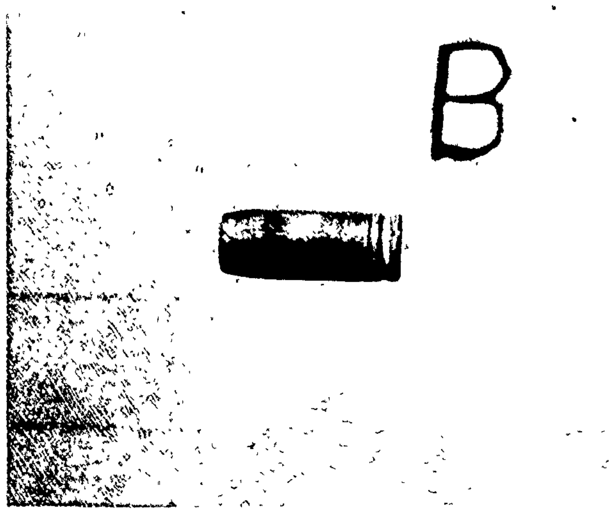


Figure 13. EG-D69-B-826/7 Series Projectile with 0.826-Inch Band Diameter, 15-Degree Forward Taper, and 7-Degree Aft Taper, In-Flight at 3,770 Feet per Second Muzzle Velocity at Ambient Conditions

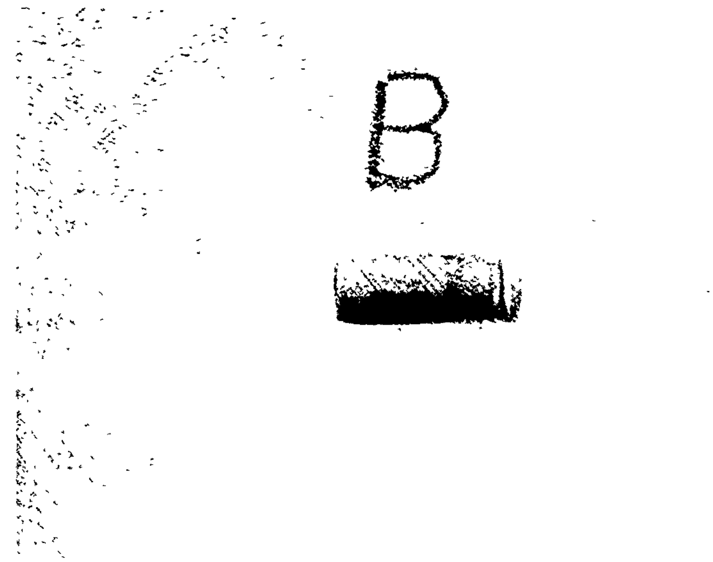


Figure 14. EG-D69-B-813/15 Series Projectile with 0.813-Inch Band Diameter, 15-Degree Fore and Aft Tapers, In-Flight at 3,763 Feet per Second Muzzle Velocity at Ambient Conditions

Figure 15. EG-D69-B-813/7 Series Projectile with 0.813-Inch Band Diameter, 15-Degree Forward Taper, 7-Degree Aft Taper, In-Flight at 3,818 Feet per Second Muzzle Velocity at Ambient Conditions

MOLDING VARIABLES

Molding parameters established by the contractor for producing nylon 12 plastic rotating bands on M55 TP projectiles were reported in AFATL-TR-74-106. It was recognized that these parameters were less than optimum, but they did produce satisfactory rotating bands. These parameters, therefore, were utilized throughout this program for the evaluation of all the other process variables. Only after the process variables were established was a study made for the optimization of the molding parameters.

Using the best conditions established for phosphating, cleaning, priming, and bonding, rotating bands were molded to projectiles with a wide range of molding parameters. Variables studied included the effects of the projectile preheat temperature, the mold temperature, the heating cylinder temperatures, the molding pressures, the cycle times, the injection rate, the screw speed, and the percentage of reprocessed material mixed with virgin molding material. The effects of annealing after molding were also investigated. Table 13 itemizes the parameters used in conjunction with a 200-ton clamp force, reciprocating screw, 6-ounce capacity Buhler injection molding press, and a total of 293 projectiles of the various combination were manufactured. Projectile series 115549-1 of Table 13 reflects the molding conditions originally developed.

The projectiles were submitted to the sponsor for test, and the results of firing trials on these units are as shown on Table 14. Microflash photographs were taken of each projectile, and they were carefully studied for defects. Major defects were classified as those relating to structural failure, and they included discarding, lift-off, chipping, and flaking. Minor defects were classified as those relating to non-structural failures, and they included slivering, feathering, fringing, and wear. Major defects resulted in the rejection of the specimen. Minor defects were subjectively rated as slight (S), moderate (M), or heavy (H). The ratings are as shown in Table 14.

A rating number was established for each projectile series by arbitrarily assigning a weighting factor to each minor defect. A no-defect category was assigned zero, a slight defect was assigned 3, a moderate defect was assigned 6, and a heavy defect was assigned 9. At each temperature and velocity condition the defect factors were summed. It was further assumed that defects worsen as the kinetic energy of the projectile increased. Since the kinetic energy is proportional to the square of the muzzle velocity, a scaling factor, consisting of the square of the quotient of the target velocity (4, 000 feet per second) divided by the average velocity of the projectiles at each temperature, was used to multiply the total defect points at each temperature. These products at each velocity and temperature were then summed to form the numerical rating for each projectile. The developed rating numbers are as shown in Table 14.

An arbitrary numerical rating number of 40 was selected as the upper limit value for acceptance of projectiles. This level permits the use of up to 50 percent reprocessed material mixed with virgin stock for use in molding. This permits the minimizing of scrap losses in a production process. With these levels in mind contractor process specification DRPS 6046.3.4 was prepared to reflect the suitable molding conditions, and a copy thereof is included herein. Figures 16 through 45 illustrate the effects of the molding variables on ballistic performance.

TABLE 13. MOLDING VARIABLES: 115549, 115550, AND 118326 PROJECTILE SERIES

Projectile Identification No.	Projectile Preheat °F	Mold Temperature, °F	Heat Zone Temperature Front °F	Center °F	Rear °F	Nozzle %	Molding Pressure, kpsi Injection	Hold	Back	Cycle Timers, seconds Inject	Hold	Closed	Injection Rate	Screw Speed	Cushion inches	Regrind Percentage	Post molding Processes*
115549- 1	290	280	435	435	410	80	18.0	12.0	3.5	5	10	30	1	7	0.25	0	A
115549- 2	290	250	435	435	410	80	18.0	12.0	3.5	2	26	6	1	7	0.25	0	A
115549- 3	290	280	435	435	410	80	18.0	12.0	3.5	5	10	30	2	7	0.25	0	A
115549- 4	290	280	435	435	410	80	16.5	11.0	3.5	5	10	30	3	7	0.25	0	A
115549- 5	290	280	435	435	410	80	14.5	9.5	3.5	5	10	30	5	7	0.25	0	A
115549- 6	290	250	435	435	410	80	18.0	12.0	3.5	5	10	30	1	7	0.25	0	A
115549- 7	290	225	435	435	410	80	18.0	12.0	3.5	5	10	30	1	7	0.25	0	A
115549- 8	290	200	435	435	410	80	18.0	12.0	3.5	5	10	30	1	7	0.25	0	A
115550- 9	290	150	435	435	410	80	18.0	12.0	3.5	5	10	30	1	7	0.25	0	A
115550-10	290	100	435	435	410	80	18.0	12.0	3.5	5	10	30	1	7	0.25	0	A
115550-11	75	280	435	435	410	80	18.0	12.0	3.5	5	10	30	1	7	0.25	0	A
115550-12	175	280	435	435	410	80	18.0	12.0	3.5	5	10	30	1	7	0.25	0	A
115550-13	225	280	435	435	410	80	18.0	12.0	3.5	5	10	30	1	7	0.25	0	A
115550-14	375	280	435	435	410	80	18.0	12.0	3.5	2	40	6	2	7	0.25	0	A
115550-15	290	280	435	435	410	80	16.5	9.5	3.5	5	10	30	1	7	0.25	0	A
115550-16	290	280	435	435	410	80	13.5	7.5	3.5	5	10	30	1	7	0.25	0	A
115550-17	290	280	435	435	410	80	11.0	5.0	3.5	5	10	30	1	7	0.25	0	A
115550-18	290	280	435	435	410	80	8.5	5.0	3.5	5	10	30	1	7	0.25	0	A
115550-19	290	280	435	435	410	80	18.0	12.0	3.5	5	10	30	1	7	0.25	25	A
115550-20	290	280	435	435	410	80	18.0	12.0	3.5	5	10	30	1	7	0.25	50	A
115550-21	290	280	435	435	410	80	18.0	12.0	3.5	5	10	30	1	7	0.25	75	A
115550-22	290	280	435	435	410	80	18.0	12.0	3.5	5	10	30	1	7	0.25	100	A
118326-23	290	280	375	375	375	75	18.0	12.0	3.5	5	10	30	1	7	0.25	0	A
118326-24	290	280	390	390	390	75	18.0	12.0	3.5	5	10	30	1	7	0.25	0	A
118326-25	290	280	410	410	410	80	18.0	12.0	3.5	5	10	30	1	7	0.25	0	A
118326-26	290	280	450	440	420	80	18.0	12.0	3.5	5	10	30	1	7	0.25	0	A
118326-27	290	280	475	460	460	80	18.0	12.0	3.5	5	10	30	1	7	0.25	0	A
118326-28	290	280	435	435	410	80	18.0	12.0	3.5	5	10	30	1	3	0.25	0	A
118326-29	290	280	435	435	410	80	18.0	12.0	3.5	5	10	30	1	5	0.25	0	A
118326-30	175	200	435	435	410	80	18.0	12.0	3.5	5	10	30	1	7	0.25	0	A
118326-31	75	75	435	435	410	80	18.0	12.0	3.5	5	10	30	1	7	0.25	0	A
118326-32*	290	280	435	435	410	80	18.0	12.0	3.5	5	10	30	1	7	0.25	0	B

Post Molding Processes:
A = Induction bonding
B = Oven annealing and oven bonding

* Baseline Process

TABLE 14. FIRING TEST RESULTS: 115549, 115550, AND 118326 PROJECTILE SERIES (MOLDING VARIABLES STUDY)

Projectile Ident. No.	Qty.	Eglin Shot Nos.	Test Temp. °F	Muzzle Velocity, fps Range	Muzzle Velocity, fps Avg.	Defects: Major (A) Discard or Lift-off	Major (A) Chips or Flakes	Minor (B) Slivers and Feathers	Minor (B) Forward Fringe	Minor (B) Aft Fringe	Minor (B) Wear	Numerical Rating (C)
115549-1	4	3090 - 3093	160	3872 - 3944	3895			S	S	S	S	
(Baseline)	3	3000 - 3002	ambient	3681 - 3770	3725			S		S	S	29.4
	3	3203 - 3205	-65	3868 - 3895	3884				S	S		
115549-2	4	3094 - 3097	160	3839 - 3914	3872				S	S	S	
	3	3003 - 3005	ambient	3750 - 3770	3763			M	S	S	S	29.7
	3	3206 - 3208	-65	3875 - 3914	3892					S		
115549-3	4	3098 - 3101	160	3875 - 3891	3885			S	S	S	S	
	3	3006 - 3008	ambient	3740 - 3790	3765			S		S	S	29.3
	3	3209 - 3211	-65	3832 - 3865	3852				S	S		
115549-4	4	3102 - 3105	160	3812 - 3872	3839			S	S	S	S	
	3	3009 - 3011	ambient	3760 - 3786	3770			S		S	M	36.1
	3	3212 - 3214	-65	3839 - 3918	3881				M	S		
115549-5	4	3106 - 3109	160	3862 - 3908	3880			H	S	M	S	
	3	3012 - 3014	ambient	3675 - 3717	3700			S		M	M	49.4
	3	3215 - 3217	-65	3862 - 3888	3876				M	S		
115549-6	4	3110 - 3113	160	3868 - 3898	3878				S	S	S	
	3	3015 - 3017	ambient	3776 - 3790	3784			S		S	S	29.4
	3	3218 - 3220	-65	3832 - 3881	3849				M	S		
115549-7	4	3114 - 3117	160	3862 - 3895	3877			M	S	S	S	
	3	3018 - 3020	ambient	3737 - 3865	3786					S	M	35.7
	3	3221 - 3223	-65	3842 - 3881	3862				M	S		

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TABLE 14. FIRING TEST RESULTS: 115549, 115550, AND 118326 PROJECTILE SERIES (MOLDING VARIABLES STUDY) (CONTINUED)

Projectile Ident. No.	Qty.	Eglin Shot Nos.	Test Temp. °F	Muzzle Velocity, fps Range	Muzzle Velocity, fps Avg.	Defects Major (A) Discard or Lift-off	Defects Major (A) Chips or Flakes	Defects Minor (B) Slivers and Feathers	Defects Minor (B) Forward Fringe	Defects Minor (B) Aft Fringe	Defects Minor (B) Wear	Numerical Rating (C)
115549-8	4	3118 - 3121	160	3839 - 3875	3859		X	S	S	M	M	X
	3	3021 - 3023	ambient	3760 - 3849	3795				S	M	M	
	3	3224 - 3226	-65	3845 - 3865	3857				H	M		
115549-9	4	3122 - 3124	160	3835 - 3849	3841		X		M	S	M	X
	3	3024 - 3026	ambient	3744 - 3776	3760				S	S	M	
	3	3227 - 3229	-65	3868 - 3888	3879				H	M		
115550-10	4	3125 - 3128	160	3793 - 3852	3832	X			M	M	M	X
	3	3027 - 3029	ambient	3750 - 3793	3779	X	X		M	H	M	
	3	3230 - 3232	-65	3809 - 3852	3832		X		M	M		
115550-11	4	3129 - 3132	160	3806 - 3839	3820				S	S	S	X
	3	3030 - 3032	ambient	3819 - 3839	3832		X		S	S	M	
	3	3233 - 3235	-65	3898 - 3914	3904				M	S		
115550-12	4	3133 - 3136	160	3809 - 3865	3834			M		S	S	32.6
	3	3033 - 3035	ambient	3796 - 3832	3812			M		S	S	
	3	3236 - 3238	-65	3872 - 3898	3886				S	S		
115550-13	4	3137 - 3140	160	3852 - 3872	3860			M	S	S	S	35.8
	3	3036 - 3038	ambient	3803 - 3822	3810			M		S	S	
	3	3239 - 3241	-65	3822 - 3859	3842				S	S		
115550-14	3	3141 - 3143	160	3839 - 3872	3852			M		S	S	38.6
	3	3039 - 3041	ambient	3819 - 3826	3822			M		S	S	
	3	3242 - 3244	-65	3849 - 3944	3909				M	M		
115550-15	4	3144 - 3147	160	3839 - 3927	3879			M		S	S	32.1
	3	3042 - 3044	ambient	3816 - 3849	3835			S		M	S	
	3	3245 - 3247	-65	3898 - 3940	3906				S	S		
115550-16	4	3148 - 3151	160	3934 - 3986	3950			S		S	M	50.9
	3	3045 - 3047	ambient	3826 - 3858	3842			M	M		S	
	3	3248 - 3250	-65	3858 - 3895	3877			M	H	M		

TABLE 14. FIRING TEST RESULTS: 115549, 115550, AND 118326 PROJECTILE SERIES (MOLDING VARIABLES STUDY) (CONTINUED)

Projectile Ident. No.	Qty.	Eglin Shot Nos.	Test Temp. °F	Muzzle Velocity, fps		Defects						Numerical Rating (C)
						Major (A)		Minor (B)				
				Range	Avg.	Discard or Lift-off	Chips or Flakes	Slivers and Feathers	Forward Fringe	Aft Fringe	Wear	
115550-17	4	3148 - 3151	160	3839 - 3977	3891			M	M	S	S	
	3	3048 - 3050	ambient	3806 - 3839	3820			M	S	S	S	48.4
	3	3251 - 3253	-65	3809 - 3888	3855			M	S	S		
115550-18	4	3156 - 3159	160	3891 - 3977	3928			H	S	S	S	
	3	3051 - 3053	ambient	3750 - 3852	3817			M	S	S	S	48.0
	3	3254 - 3256	-65	3829 - 3904	3865			S	M	S		
115550-19	3	3160 - 3162	160	3793 - 3898	3839			M	S	S	S	
	3	3054 - 3056	ambient	3835 - 3855	3842			S	S	S	S	38.8
	3	3257 - 3259	-65	3819 - 3960	3890				M	S		
115550-20	4	3163 - 3166	160	3826 - [illegible]54	3878			S	S	S	S	
	3	3057 - 3059	ambient	3816 - 3839	3830			S	S	S	S	38.6
	3	3260 - 3262	-65	3849 - 3918	3875			S	M	S		
115550-21	4	3167 - 3170	160	3819 - 3852	3833			S	S	S	S	
	3	3060 - 3062	ambient	3858 - 3885	3869			M	S	M	S	44.8
	3	3263 - 3265	-65	3898 - 3963	3922				M	M		
115550-22	3	3171 - 3173	160	3845 - 3931	3885			H	S	S	M	
	3	3063 - 3065	ambient	3809 - 3865	3830			H	S	M	S	64.1
	3	3266 - 3268	-65	3878 - 3914	3899			M	M	M		
118326-23	4	3174 - 3177	160	3829 - 3944	3868			S	S	S	S	
	3	3066 - 3068	ambient	3806 - 3878	3851			H		S	S	41.7
	3	3269 - 3271	-65	3835 - 3944	3884				M	M		
118326-24	3	3178 - 3180	160	3858 - 3885	3872			M	S	S	S	
	3	3069 - 3971	ambient	3799 - 3806	3802			M			M	32.4
	3	3272 - 3274	-65	3839 - 3895	3875				S	S		

TABLE 14. FIRING TEST RESULTS: 115549, 115550, AND 118326 PROJECTILE SERIES (MOLDING VARIABLES STUDY) (CONCLUDED)

Projectile Ident. No.	Qty.	Eglin Shot Nos.	Test Temp. °F	Muzzle Velocity, fps Range	Muzzle Velocity, fps Avg.	Defects: Major (A) Discard or Lift-off	Major (A) Chips or Flakes	Minor (B) Slivers and Feathers	Minor (B) Forward Fringe	Minor (B) Aft Fringe	Minor (B) Wear	Numerical Rating (C)
118326-25	4	3181 - 3184	160	3842 - 3950	3881			S	S	S	S	35.2
	3	3072 - 3074	ambient	3822 - 3904	3872			H		S	S	
	3	3275 - 3277	-65	3842 - 3878	3862				S	S		
118326-28	4	3185 - 3188	160	3809 - 3898	3846			M	S	S	S	39.1
	3	3075 - 3077	ambient	3796 - 3852	3819			M			S	
	3	3278 - 3280	-65	3829 - 3845	3840				M	M		
118326-29	4	3189 - 3192	160	3858 - 3898	3876			S	S	S	S	38.6
	3	3078 - 3080	ambient	3832 - 3691	3859			M		S	S	
	3	3281 - 3283	-65	3806 - 3885	3847			S	M	S		
118326-30	4	3193 - 3196	160	3855 - 3927	3890			M	M	M	M	X
	3	3081 - 3083	ambient	3845 - 3911	3874				M	M	S	
	3	3284 - 3286	-65	3852 - 3875	3866		X		H	H		
118326-31	3	3197 - 3199	160	3852 - 3904	3977	X		H	H	M	S	X
	3	3084 - 3086	ambient	3812 - 3875	3846	X		M	M	M	S	
	3	3287 - 3289	-65	3783 - 3839	3808	X			H	H		
118326-32	3	3200 - 3202	160	3901 - 3934	3914				S	S	S	X
	3	3087 - 3089	ambient	3809 - 3855	3837		X	M	M	M	S	
	3	3290 - 3292	-65	3862 - 3914	3891				H	H		

(A) Any major defect results in rejection.

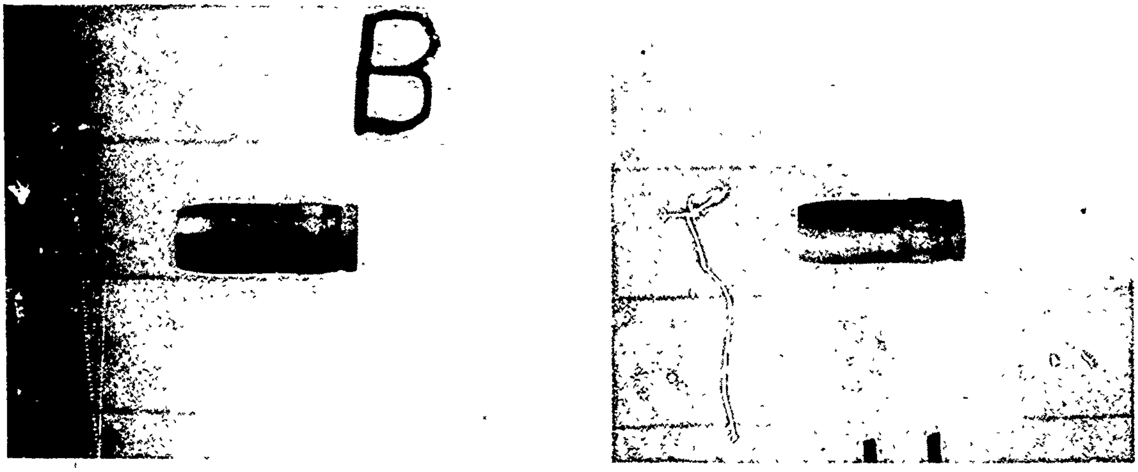
(B) Minor defects are acceptable as long as no major defect exists. Classification of mino· defects:

S = Slight indication of noted effect
M = Mod.rate indication of noted effect
H = Heavy indication of defect

(C) Rating scale:

Each "S" = 3
Each "M" = 6
Each "H" = 9

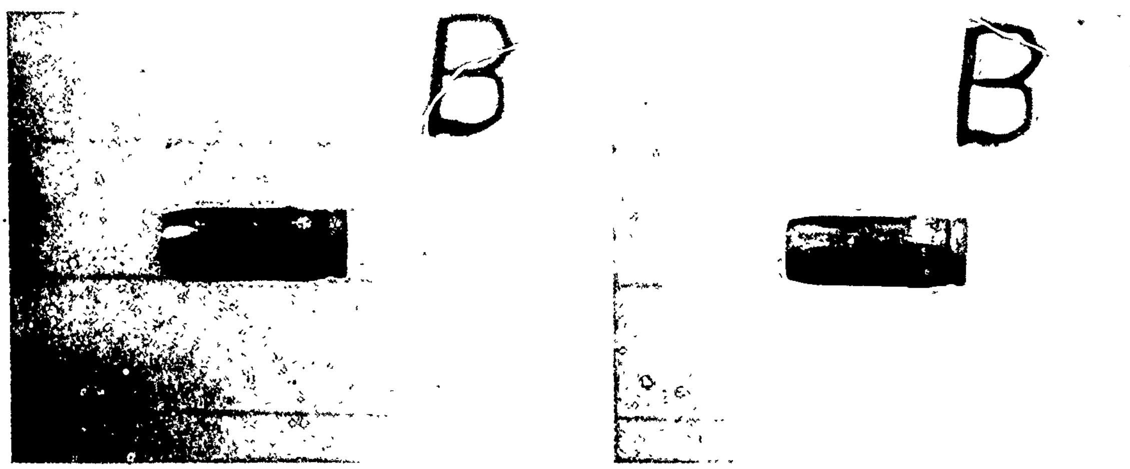
$$\text{Rating No.} = (4000)^2 \sum_{T=-65}^{T=160} \left[\frac{\text{Minor defect points}}{\overline{V}_T^{\,2}} \right]$$



3,895 Feet per Second
at -65°F

3,944 Feet per Second
at 160°F

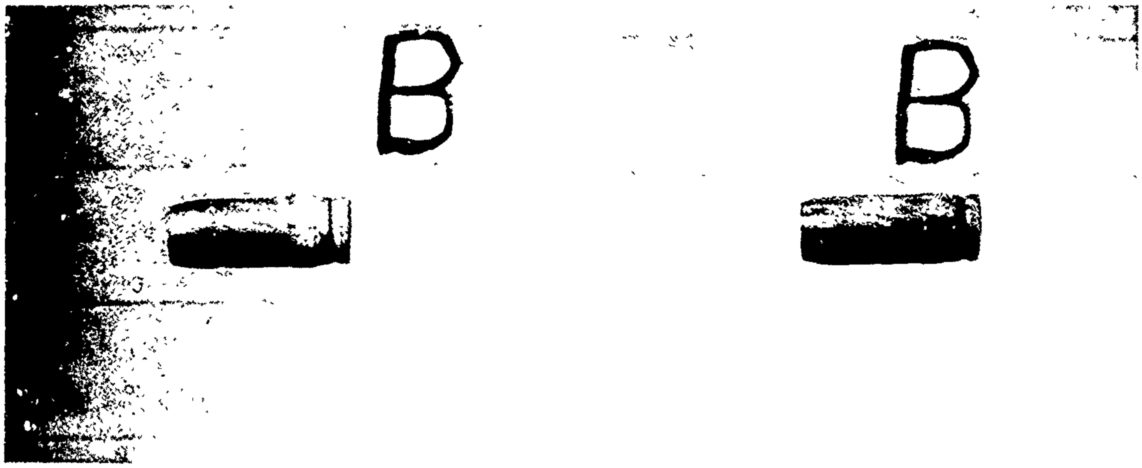
Figure 16. Molding Variables Study: 115549-1 Series Projectile



3,888 Feet per Second
at -65°F

3,914 Feet per Second
at 160°F

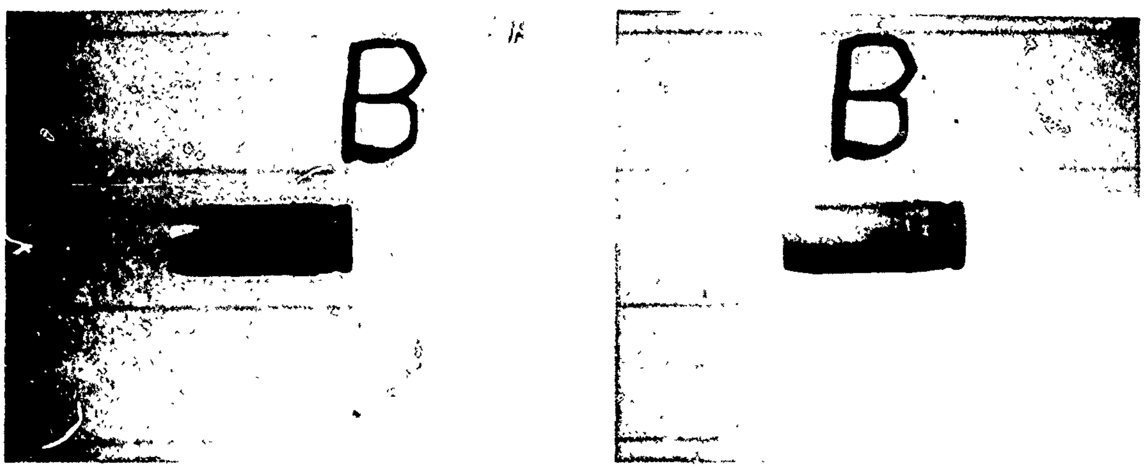
Figure 17. Molding Variables Study: 115549-2 Series Projectile



3, 865 Feet per Second at -65°F

3, 855 Feet per Second at 160°F

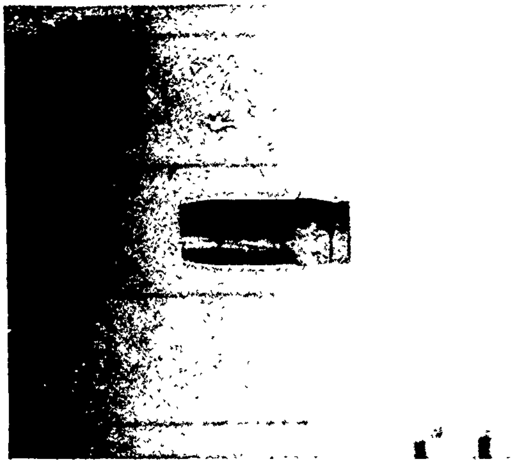
Figure 18. Molding Variables Study: 115549-3 Series Projectile



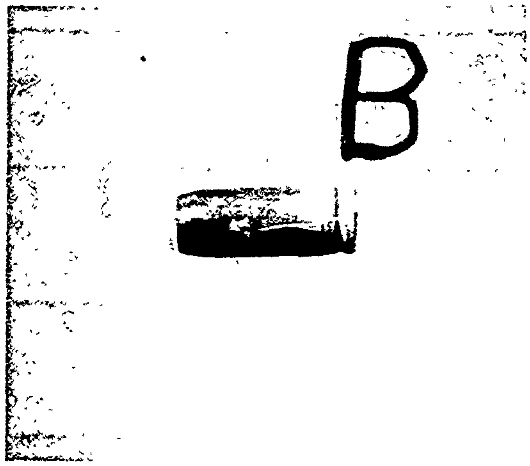
3, 839 Feet per Second at -65°F

3, 812 Feet per Second at 160°F

Figure 19. Molding Variables Study: 115549-4 Series Projectile

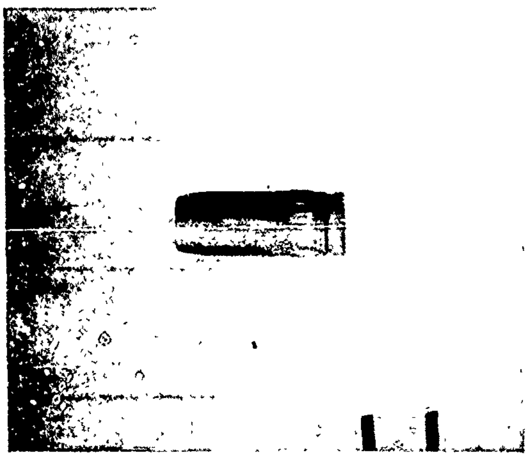


3,888 Feet per Second
at -65°F



3,862 Feet per Second
at 160°F

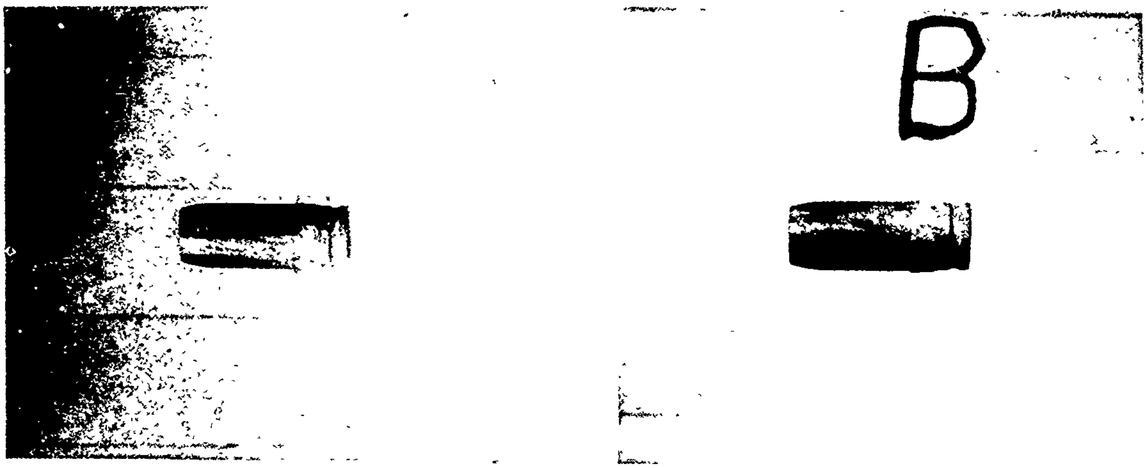
Figure 20. Molding Variables Study: 115549-5 Series Projectile



3,835 Feet per Second
at -65°F

3,872 Feet per Second
at 160°F

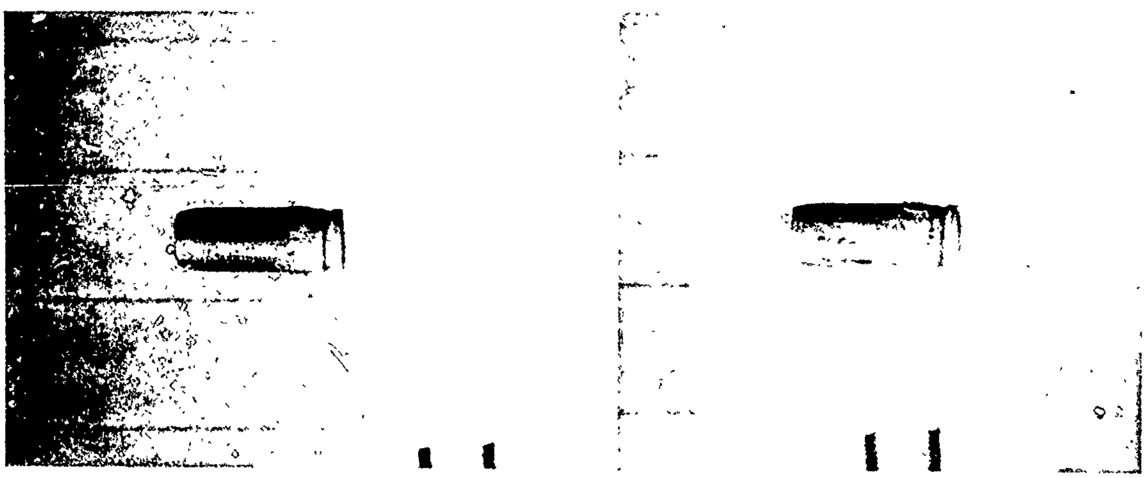
Figure 21. Molding Variables Study: 115549-6 Series Projectile



3,842 Feet per Second
at -65°F

3,872 Feet per Second
at 160°F

Figure 22. Molding Variables Study: 115549-7 Series Projectile



3,865 Feet per Second
at -65°F

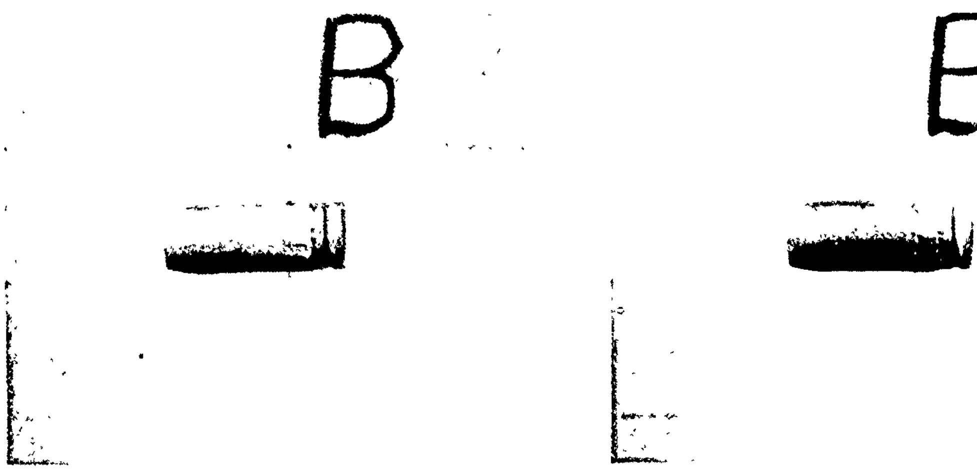
3,839 Feet per Second
at 160°F

Figure 23. Molding Variables Study: 115549-8 Series Projectile

3,881 Feet per Second
at -65°F

3,849 Feet per Second
at 160°F

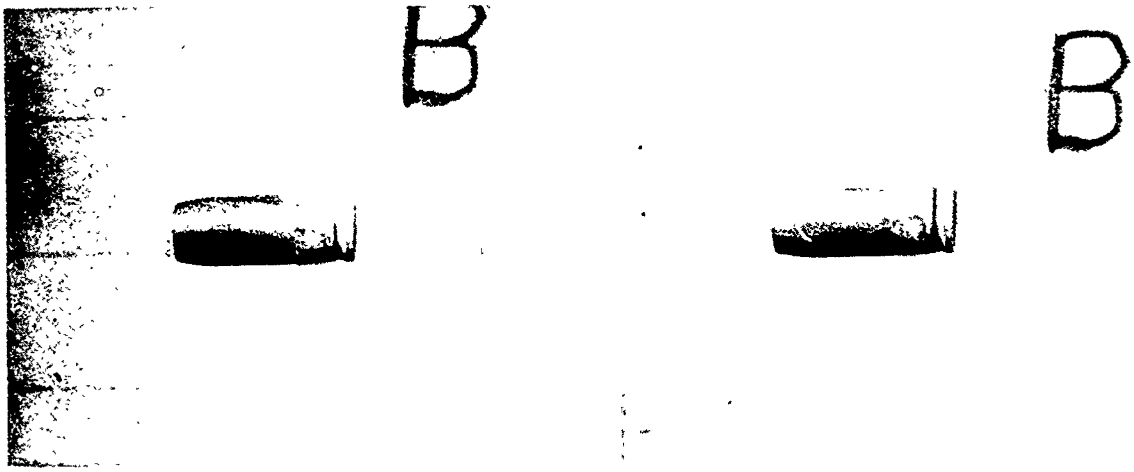
Figure 24. Molding Variables Study: 115549-9 Series Projectile



3,809 Feet per Second
at -65°F

3,793 Feet per Second
at 160°F

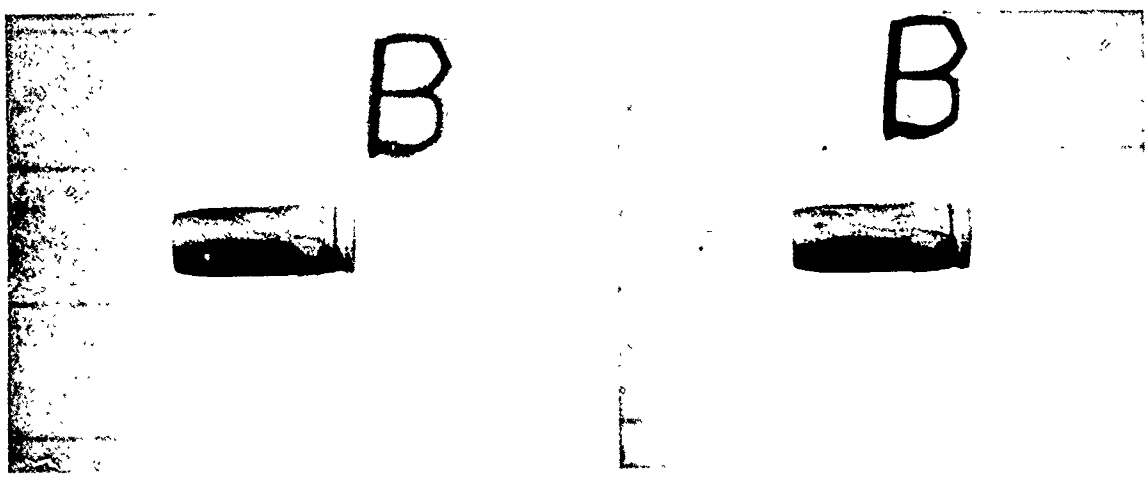
Figure 25. Molding Variables Study: 115550-10 Series Projectile



3,898 Feet per Second
at -65°F

3,839 Feet per Second
at 70°F

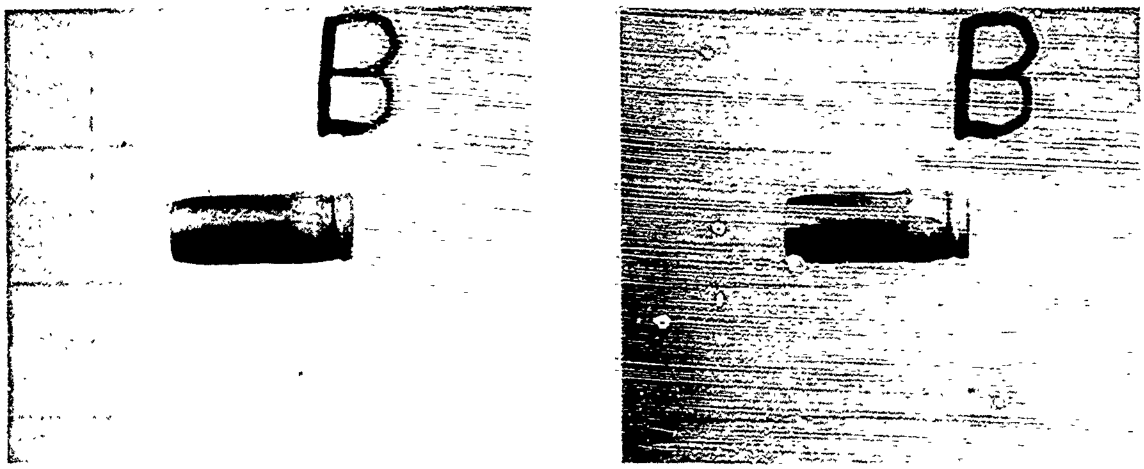
Figure 26. Molding Variables Study: 115550-11 Series Projectile



3,888 Feet per Second
at -65°F

3,865 Feet per Second
at 160°F

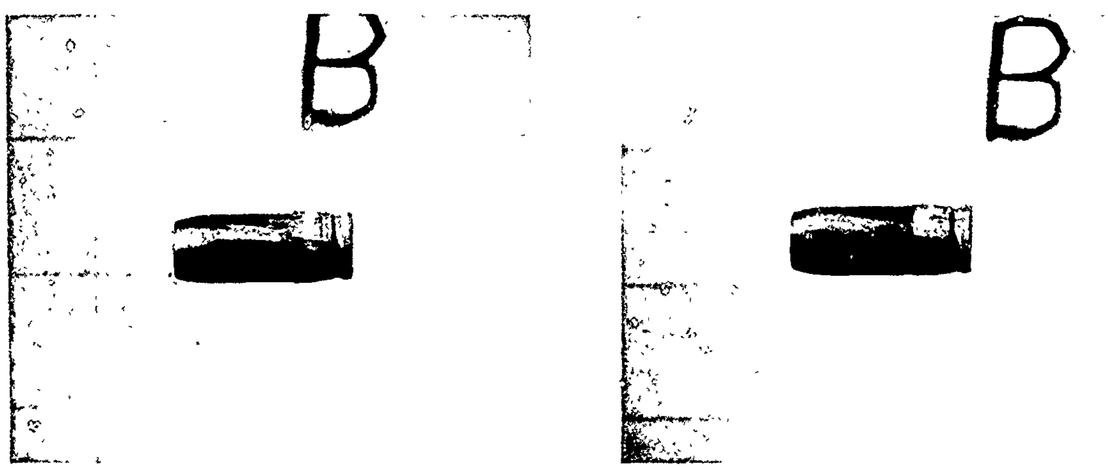
Figure 27. Molding Variables Study: 115550-12 Series Projectile



3,822 Feet per Second at -65°F

3,858 Feet per Second at 160°F

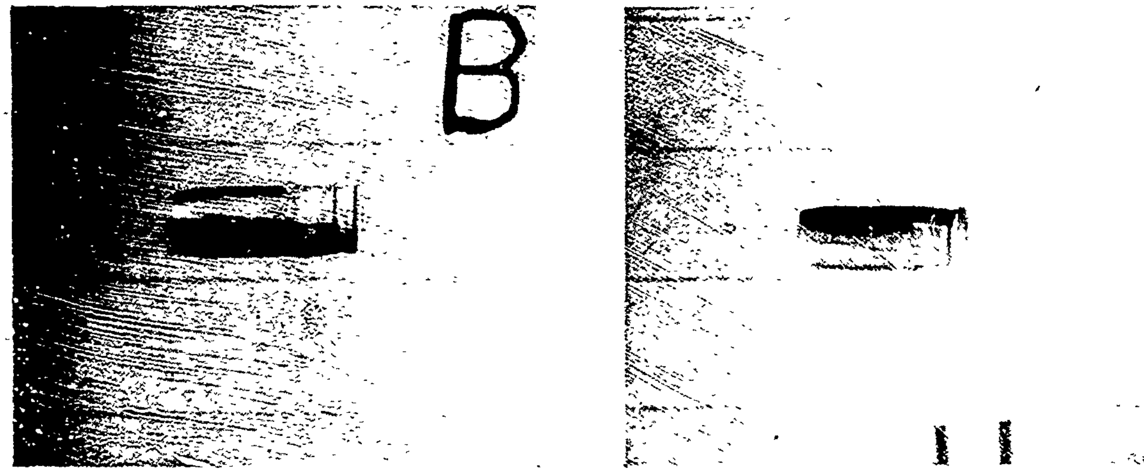
Figure 28. Molding Variables Study: 115550-13 Series Projectile



3,944 Feet per Second at -65°F

3,839 Feet per Second at 160°F

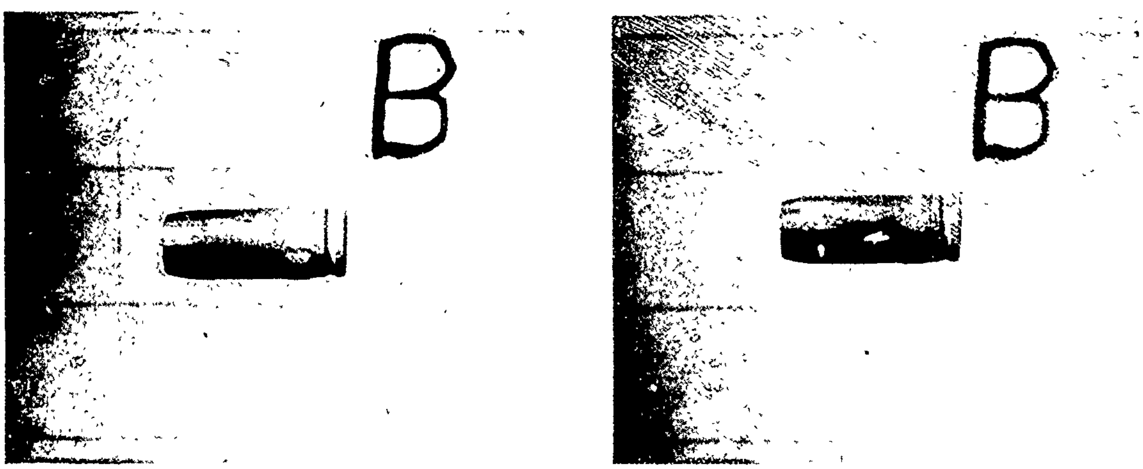
Figure 29. Molding Variables Study: 115550-14 Series Projectile



3,940 Feet per Second at -65°F

3,858 Feet per Second at 160°F

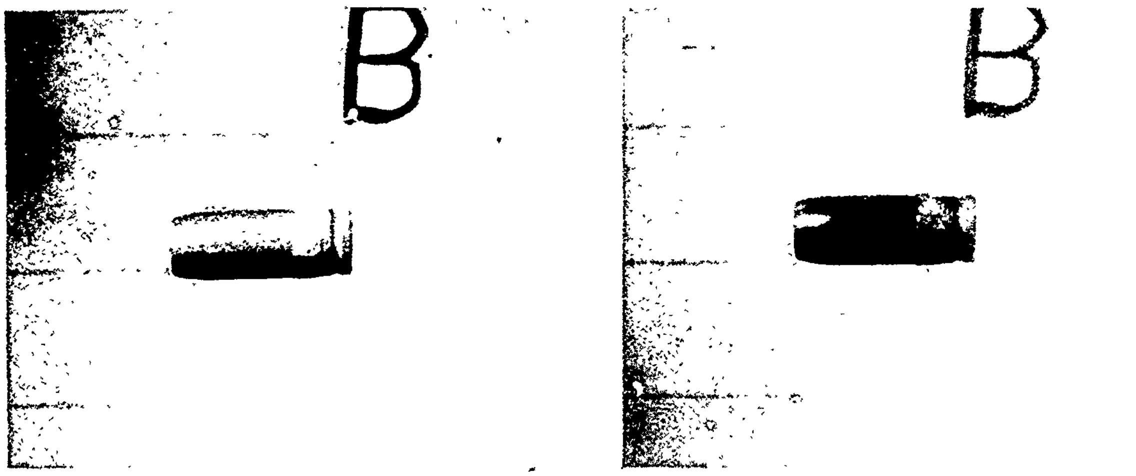
Figure 30. Molding Variables Study: 115550-15 Series Projectile



3,878 Feet per Second at -65°F

3,934 Feet per Second at 160°F

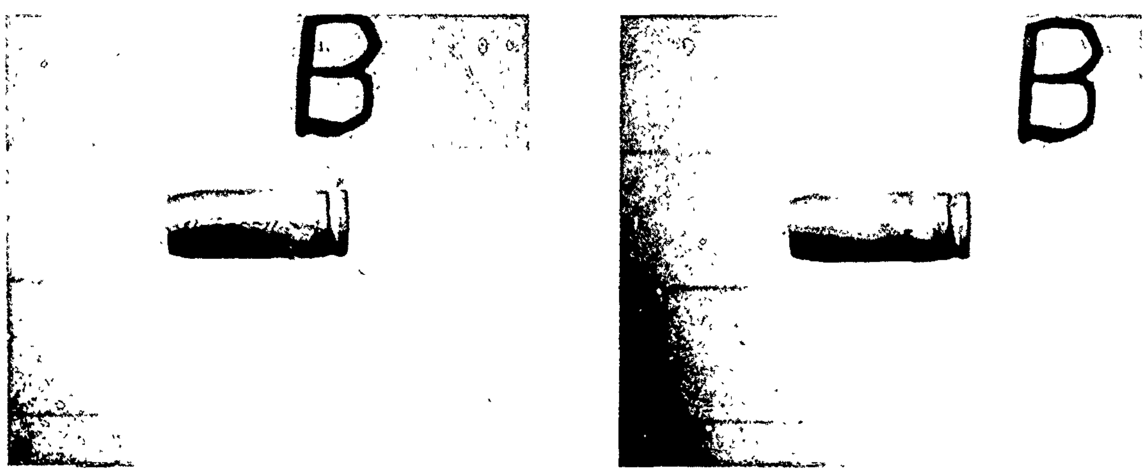
Figure 31. Molding Variables Study: 115550-16 Series Projectile



3,888 Feet per Second at -65°F

3,891 Feet per Second at 160°F

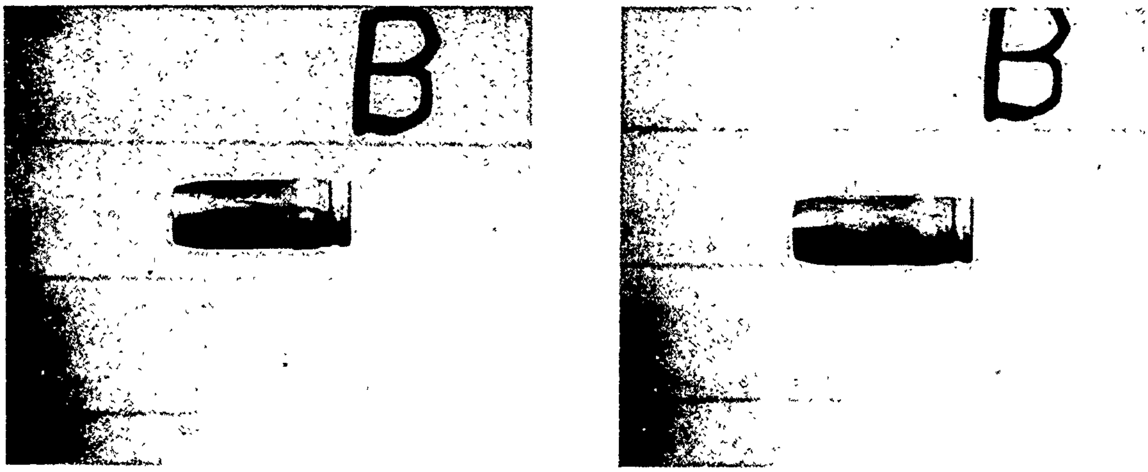
Figure 32. Molding Variables Study: 115550-17 Series Projectile



3,862 Feet per Second at -65°F

3,921 Feet per Second at 160°F

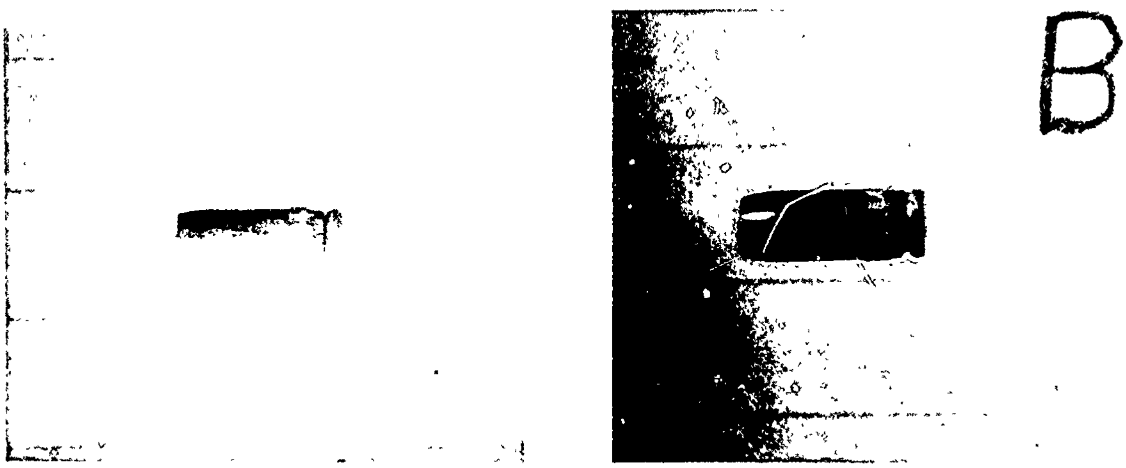
Figure 33. Molding Variables Study: 115550-18 Series Projectile



3, 960 Feet per Second
at -65°F

3, 826 Feet per Second
at 160°F

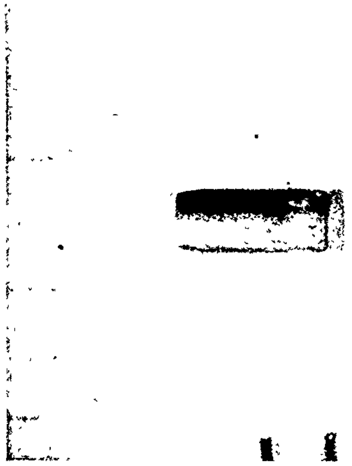
Figure 34. Molding Variables Study: 115550-19 Series Projectile



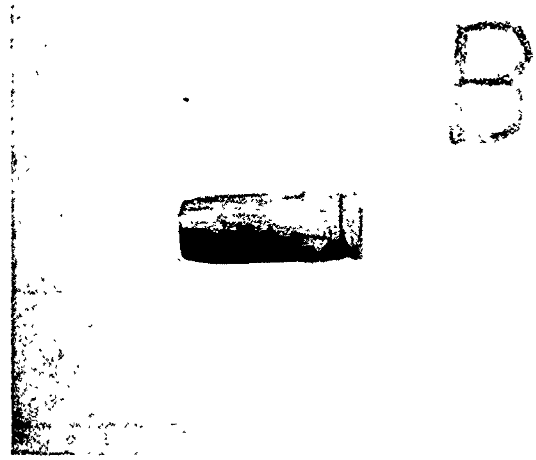
3, 849 Feet per Second
at -65°F

3, 954 Feet per Second
at 160°F

Figure 35. Molding Variables Study: 115550-20 Series Projectile

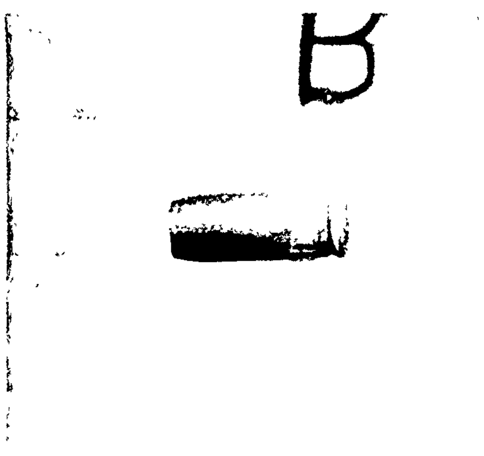


3,904 Feet per Second
at -65°F

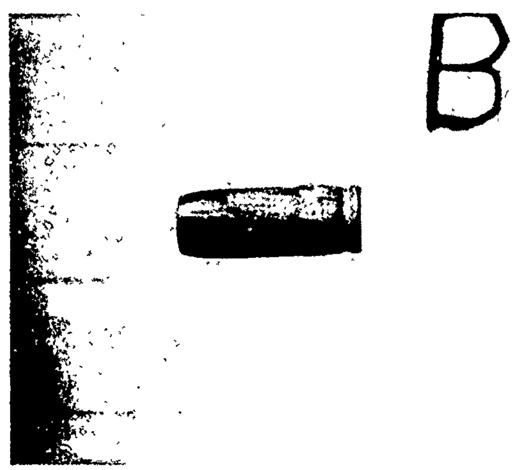


3,819 Feet per Second
at 160°F

Figure 36. Molding Variables Study: 115550-21 Series Projectile

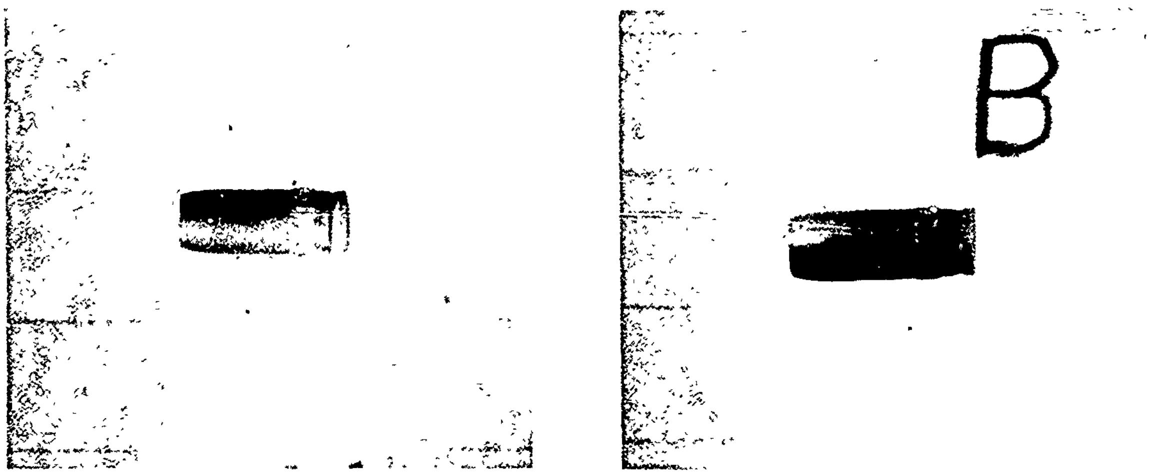


3,878 Feet per Second
at -65°F



3,845 Feet per Second
at 160°F

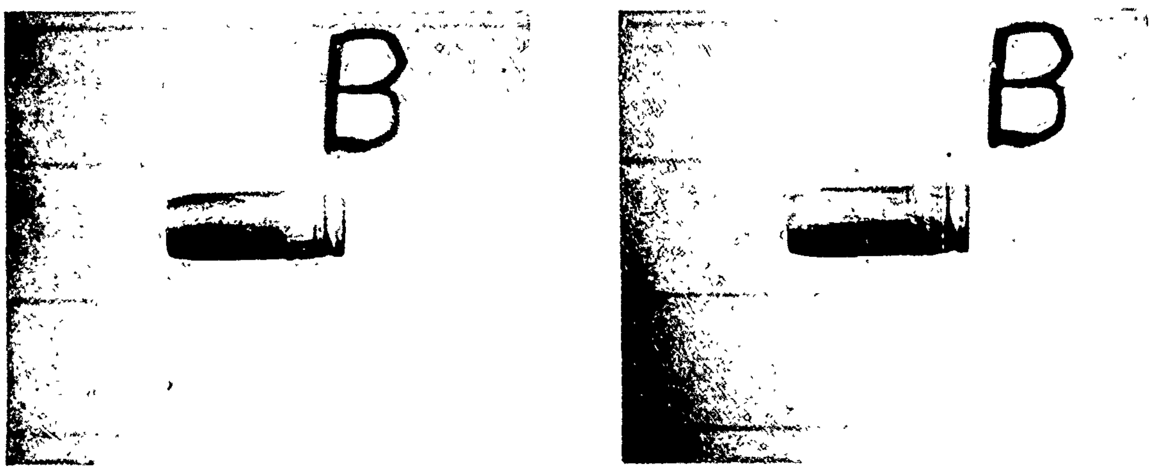
Figure 37. Molding Variables Study: 115550-22 Series Projectile



3,872 Feet per Second
at -65°F

3,852 Feet per Second
at 160°F

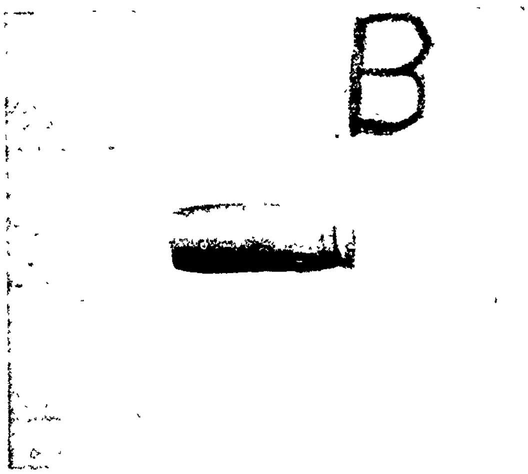
Figure 38. Molding Variables Study: 118326-23 Series Projectile



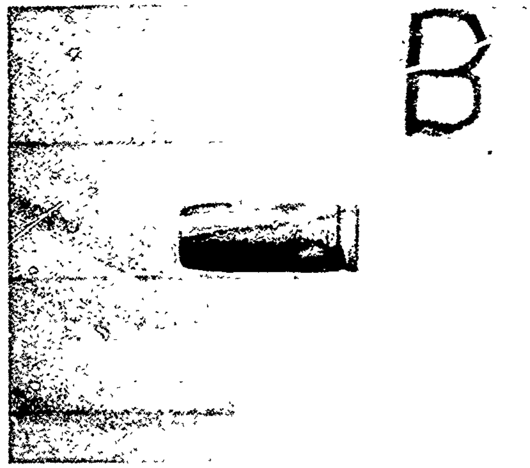
3,895 Feet per Second
at -65°F

3,858 Feet per Second
at 160°F

Figure 39. Molding Variables Study: 118326-24 Series Projectile

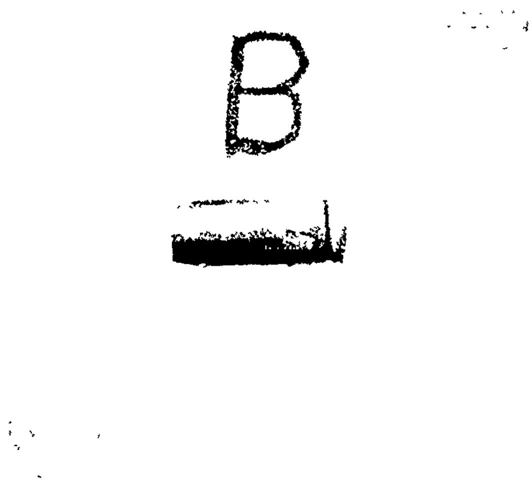


3,878 Feet per Second
at -65°F

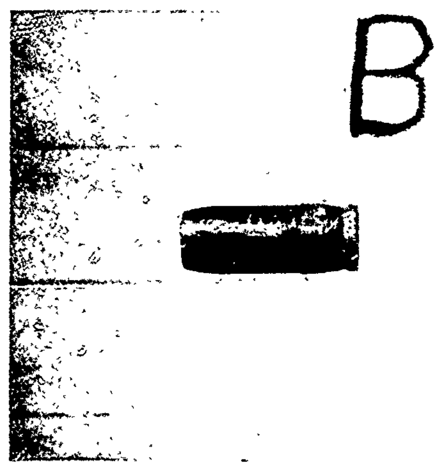


3,888 Feet per Second
at 160°F

Figure 40. Molding Variables Study: 118326-25 Series Projectile

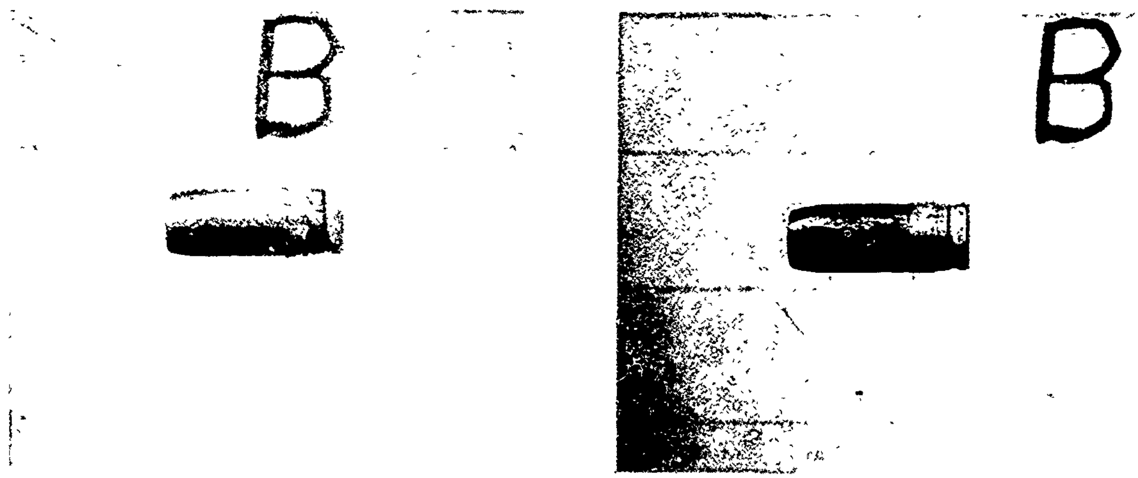


3,845 Feet per Second
at -65°F



3,816 Feet per Second
at 160°F

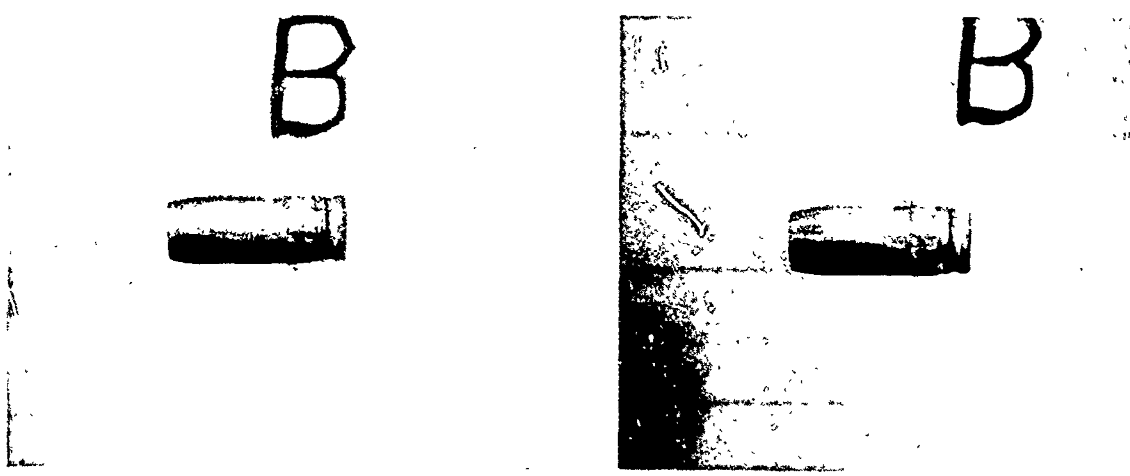
Figure 41. Molding Variables Study: 118326-28 Series Projectile



3,806 Feet per Second
at -65°F

3,898 Feet per Second
at 160°F

Figure 42. Molding Variables Study: 118326-29 Series Projectile



3,872 Feet per Second
at -65°F

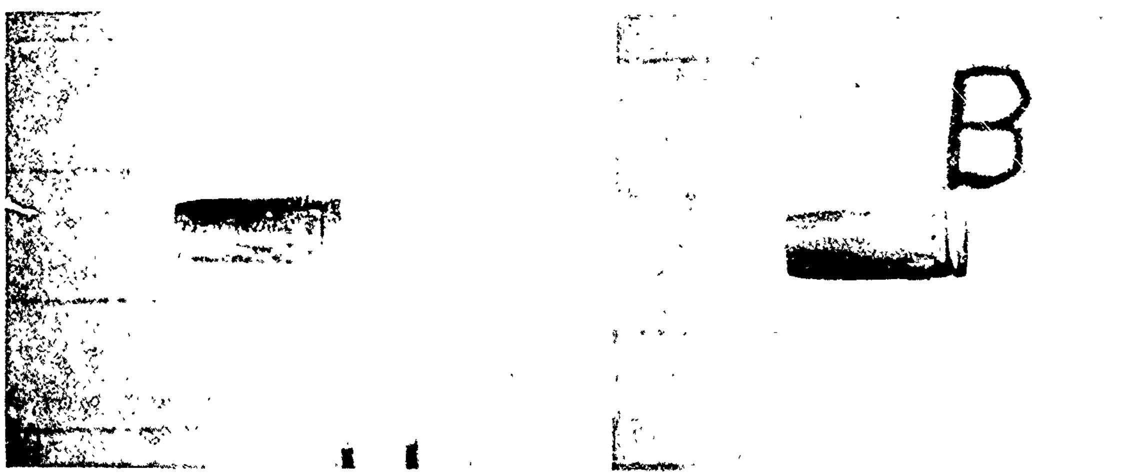
3,855 Feet per Second
at 160°F

Figure 43. Molding Variables Study: 118326-30 Series Projectile

3,839 Feet per Second
at -65°F

3,904 Feet per Second
at 160°F

Figure 44. Molding Variables Study: 118326-31 Series Projectile



3,898 Feet per Second
at -65°F

3,855 Feet per Second
at 70°F

Figure 45. Molding Variables Study: 118326-32 Series Projectile

COATING STUDIES

After all geometry, materials, and process parameters had been specified, a lot of 1,000 preproduction projectiles were manufactured with nylon 12 rotating bands and submitted to the sponsor for final test. During the course of the testing it was found that units which had been subjected to a 28-day, temperature and humidity cycling in accordance with MIL-STD-331, Test 105, failed subsequent firing tests in the M61 Mann barrel. Prior to the firing tests and after temperature and humidity conditioning, it was noted that considerable corrosion was evident under the bands, principally at the fore and aft edges of the band seat. Such was not the case when projectiles had been subjected to 28 days of cycling in accordance with MIL-STD-810B, Method 507, Procedure IV, this testing sequence having been used for the earlier surface preparation studies.

The primary difference between the two test methods was the temperature range. In MIL-STD-331 cycling, the temperature range was from -80°F to 160°F, while maintaining a 95-percent relative humidity. The coefficient of linear expansion for nylon 12 is approximately an order of magnitude greater than the steel projectile body. As the projectile cools to the lower limit, an axial tensile stress is developed in the plastic rotating band as a result of the difference in coefficients of expansion. This, in turn, places the bonded interface between the edges of the band and the ends of the seat in tension, which is a worst condition for any bonded joint. The bond most likely fails at this point, somewhat minutely, as a result of this differential loading, but the minute failure creates a path for moisture inception at the ends of the bands as the projectile is passed from the lower tempeature limit to conditions of higher temperatures and the onset of humidity. As the projectile is passed into the lower temperature region in the next cycle, the entrapped moisture expands during its phase change to further separate the plastic band by a peel mode from the seat edges. Repetition of the cycling further compounds the situation, ever widening the moisture path, and exposes now unprotected band seats to corrosion. Corrosion inception into the band seat neck ensues by working under the primed interface. The result, after the 28-day cycling, is circular rings of corrosion starting at both edges and extending axially under the band. The resultant loss in bonded shear area would be sufficient to result in band seat shear failures during gun firing.

The same phenomena was not evident under temperature and humidity conditioning in accordance with MIL-STD-810B, Method 507, Procedure IV, for 28 days, where the temperature never reached the freezing point of water. Rotating bands on projectiles subjected to this conditioning were not observed to have these rings of corrosion at or under the edges of the bands.

Other causes for failure which were under consideration included differences in processing between the 1,000 preproduction units and those which had been subjected to earlier tests, and moisture permeation through the band to the seat, both of which could result in weakened bonds. It was determined that perhaps a protective coating over the bands would prevent or minimize the deleterious effects of temperature and humidity cycling.

A group of projectiles was prepared for temperature and humidity cycling tests in which protective coatings and changes in the manufacturing processes were studied. Table 15 describes the specimen tested.

TABLE 15. DESCRIPTION OF SAMPLES SUBMITTED TO TEMPERATURE AND HUMIDITY CYCLING

Projectile Ident. No.	Protective Coating	Mold Gate Type	Bonding Cycle Time, seconds	Bonding Cycle Current, milli-amperes
117625-87	Uncoated (same as 1,000 size lot)	Sub	4.25	100
117625-87C	Polyurethane Varnish	Sub	4.25	100
119603-101	Uncoated (same as earlier development units)	Ring	6.50	82
119603-101C	Epon 1001 epoxy/DETA	Ring	6.50	82
119603-102	Uncoated (same bond cycle as earlier development units)	Sub	6.50	82
119603-102C	Epon 1001 epoxy/DETA	Sub	6.50	82

The units were subjected to temperature and humidity cycling in accordance with MIL-STD-331, Test 105, for both 14 and 28 days, and in accordance with MIL-STD-810B, Method 507, Procedure IV, for 28 days. After exposure the units were visually examined for corrosion in and around the band seats. Table 16 lists the results of this examination, and it showed that no corrosion existed on units subjected to MIL-STD-810 cycling, whereas some corrosion was present on all units subjected to MIL-STD-331 cycling, whether or not a protective coating was used.

The conditioned specimen were also subjected to peel tests and impact tests to determine the effects of the temperature and humidity exposures to the bonded rotating bands. Peel testing was accomplished by axially slitting a rotating band and carefully lifting an edge of the slit from the band seat to form a peel tab. The projectile was then rotatably mounted in a test fixture, and the peel tab was grasped in the jaws of a tensile testing apparatus. As the peel tab was pulled, the band unwound from the band seat while the projectile rotated. The peel strength was measured and recorded in pounds per inch of band width. The results for some specimen are as shown in Table 17, and they illustrate a higher peel strength on units subjected to full term MIL-STD-810 cycling than either 14-day or 28-day cycling in accordance with MIL-STD-331. The effect of the coatings was not evident.

Two varieties of impact tests were used: a rifling engraving test and a falling dart test. The rifling engraving test consisted of mounting a projectile, nose down, in a section of constant twist rifled barrel, and dropping a 20-pound weight from a height of 3 feet onto the base of the projectile to drive it into the rifling, travel for a short distance, and stop abruptly against a steel plate at the base of the rifled barrel section. The set-up is as shown in Figure 46.

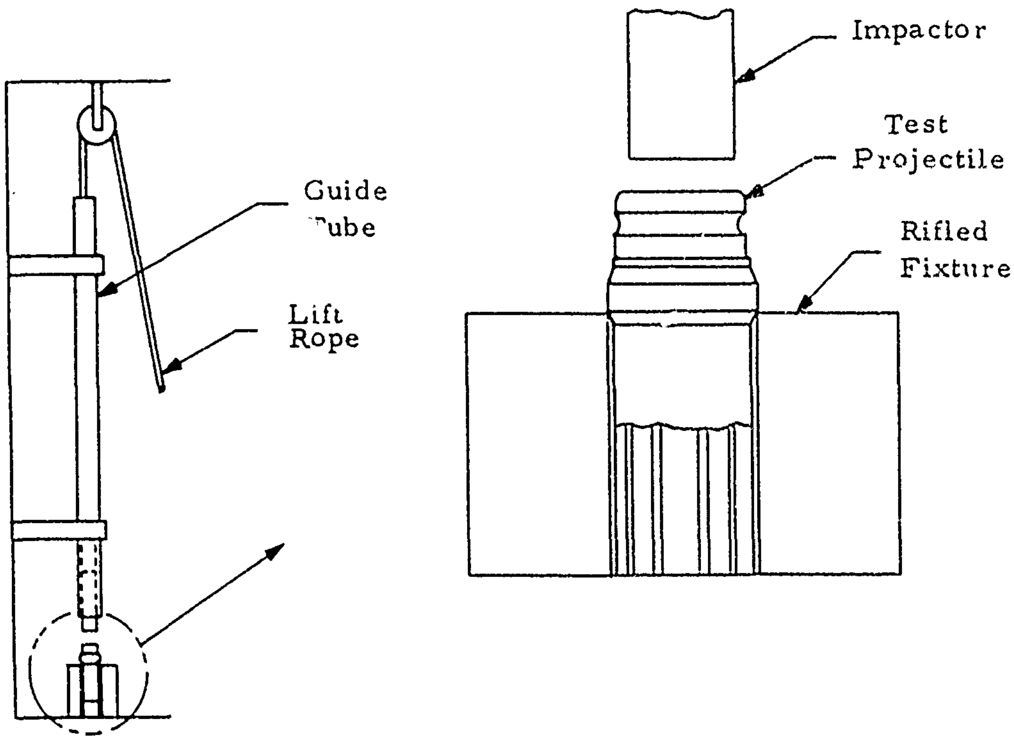


Figure 46. Rifling Engraving Test Set-Up

Following the rifling engraving test, the same test units (provided that they had passed the engraving test without debonding or discard) were subjected to a 60 foot-pound falling dart test. The testing was that which had been previously developed by the contractor and reported in AFATL-TR-74-106. The results of the two drop tests are as shown in Table 17, and they showed that units would pass these tests regardless of processing or coating variations after MIL-STD-810 temperature and humidity exposure, whereas some marginal results were evident after the MIL-STD-331 exposure.

Finally, the conditioned units were test fired. Firing trials were performed at Indiana Ordnance, Connersville, Indiana, as a part of the concurrent activities being expended as a part of Contract F33615-75-C-5226 which the contractor held with Wright-Patterson Air Force Base, Dayton, Ohio. The results, as presented in Table 17, showed that all units were satisfactory after MIL-STD-810 temperature and humidity exposure, whereas some marginal results occurred in firing after cycling in accordance with MIL-STD-331. The protective coatings were considered beneficial, but they did not completely resolve the problem. Figures 47 through 52 illustrate flight characteristics of the tested projectiles.

TABLE 16. RESULTS OF TEMPERATURE AND HUMIDITY CYCLING ON PROJECTILE SPECIMEN

Projectile Ident. No. (See Table 15)	T&H Specification	Cycle Time, Days	Results of Visual Examination
117625-87	MIL-STD-331	14	Slight ring of corrosion around forward edge of band.
		28	No different from 14-day cycle.
	MIL-STD-810	28	No noticeable defects.
117625-87C	MIL-STD-331	14	Slight ring of corrosion around forward edge of band; better than 117625-87 and 119601-102C at same cycle.
		28	No different from 14-day cycle.
	MIL-STD-810	28	No noticeable defects.
119603-101	MIL-STD-331	14	Slight ring of corrosion at forward edge.
		28	Fore and aft corrosion and debond.
	MIL-STD-810	28	No noticeable defects.
119603-101C	MIL-STD-331	14	Corrosion, but noticeable better than 119603-101 at same cycle.
		28	Same as 14-day cycle except some aft edge debond observed.
	MIL-STD-810	28	No noticeable defects.
119603-102	MIL-STD-331	14	Slight corrosion around forward edge.
		28	Some forward edge corrosion and aft edge debond.
	MIL-STD-810	28	No noticeable defects.
119603-102C	MIL-STD-331	14	Slight ring of corrosion around forward edge; not as good as 117625-87C at same cycle.
		28	Very slight forward edge corrosion.
	MIL-STD-810	28	No noticeable defects.

TABLE 17. RESULTS OF LABORATORY AND FIRING TESTS ON PROJECTILES SUBJECTED TO TEMPERATURE AND HUMIDITY CYCLING

Projectile Identification	MIL-STD-T&H Test		Band Peel Strength, lb/in		60 ft-lb Impact Tests		Firing Tests after Conditioning			
	No.	Cycle Days	Peak	Avg.	Rifle Engraving	Falling Dart	Temp. °F	Muzzle Velocity, fps Range	Muzzle Velocity, fps Avg.	Observations from Microflash Photographs
117625-87	-331	14					-65	3798-3870	3841	6 units; 1 chunking, others satisfactory.
							160	3870-3928	3905	6 units; 1 lifting off at rear, others intact but wearing.
		28			Pass	Pass	-65	3855-3884	3873	6 units; 1 chunking, others satisfactory.
							160	3862-3884	3877	4 units; 1 chunking, others intact but wearing.
	-810	28			Pass	Pass	-65	3877-3899	3887	3 units; all satisfactory.
							160	3921-3951	3936	3 units; all satisfactory.
117625-87C	-331	14	31	24			-65	3841-3884	3859	6 units; 1 chipping, others satisfactory.
							160	3906-3980	3940	6 units; all intact but wearing.
		28	37	29			-65	3877-3914	3895	5 units; 1 chunking, others satisfactory.
							160	3855-3914	3893	5 units; all intact but wearing.

TABLE 17. RESULTS OF LABORATORY AND FIRING TESTS ON PROJECTILES SUBJECTED TO TEMPERATURE AND HUMIDITY CYCLING (CONTINUED)

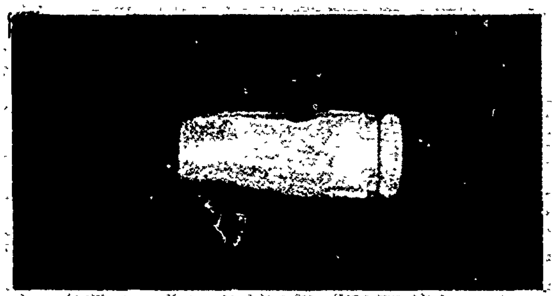
Projectile Identification	MIL-STD-T&H Test No.	MIL-STD-T&H Test Cycle Days	Band Peel Strength, lb/in Peak	Band Peel Strength, lb/in Avg.	60 ft-lb Impact Tests Rifle Engraving	60 ft-lb Impact Tests Falling Dart	Firing Tests after Conditioning Temp. °F	Muzzle Velocity, fps Range	Muzzle Velocity, fps Avg.	Observations from Microflash Photographs
117625-87C (continued)	-810	28	54	41	Pass	Pass	-65	3899-3914	3907	4 units; all satisfactory.
							160	3921-3966	3953	4 units; all satisfactory.
119603-101	-331	14					-65	3841-3862	3852	5 units; 1 slightly lifting others satisfactory.
							160	3870-3951	3892	5 units; 2 lifting slightly, others intact but wearing.
		28			Pass	Marginal	-65	3791-3906	3861	5 units; 1 lifting at rear, 2 partial discards, others satisfactory.
							160	3855-3899	3881	4 units; 1 photo only. Unit intact and satisfactory (3855 fps).
	-810	28			Pass	Pass	-65	3884-3914	3901	3 units; all satisfactory.
							160	3906-3936	3921	2 units; both intact but wearing.
119603-101C	-331	14	31	27			-65	3862-3884	3871	5 units; 2 lifting off, others satisfactory.
							160	3877-3921	3899	5 units; all intact but wearing.
		28	22	14			-65	3899-3928	3910	4 units; 2 partial discards, 1 lifting, 1 chunking.
							160	3884-3914	3897	4 units; 2 photos only. 1 lift-off, others satisfactory.

TABLE 17. RESULTS OF LABORATORY AND FIRING TESTS ON PROJECTILES SUBJECTED TO TEMPERATURE AND HUMIDITY CYCLING (CONTINUED)

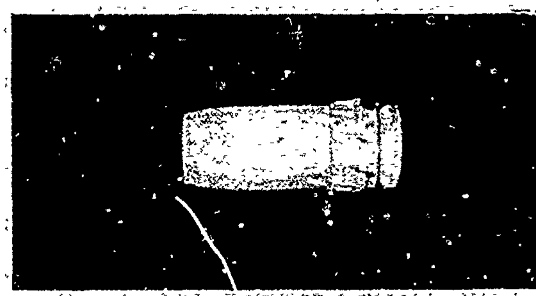
Projectile Identification	MIL-STD-T&H Test		Band Peel Strength, lb/in		60 ft-lb Impact Tests		Firing Tests after Conditioning			
	No.	Cycle Days	Peak	Avg.	Rifle Engraving	Falling Dart	Temp. °F	Muzzle Velocity, fps Range	Muzzle Velocity, fps Avg.	Observations from Microflash Photographs
119602-101C (continued)	-810	28					-65	3914-3936	3925	2 units; both satisfactory.
							160	3906-3936	3921	2 units; both satisfactory.
119603-102	-331	14					-65	3826-3877	3855	5 units; 1 partial discard, others satisfactory.
							160	3884-3906	3891	5 units; all intact but wearing.
		28			Pass	Marginal	-65	3826-3906	3880	units; 1 chunking, others satisfactory.
							160	3855-3982	3894	4 units; all intact but wearing.
	-810	28	75	59	Pass	Pass	-65			No firing tests. Samples expended in laboratory tests
							160			
119603-102C	-331	14	34	28			-65	3870-3891	3881	5 units; 2 lifting slightly, others satisfactory.
							160	3877-3899	3888	5 units; all intact but wearing.

TABLE 17. RESULTS OF LABORATORY AND FIRING TESTS ON PROJECTILES SUBJECTED TO TEMPERATURE AND HUMIDITY CYCLING (CONCLUDED)

Projectile Identification	MIL-STD-T&H Test		Band Peel Strength, lb/in		60 ft-lb Impact Tests		Firing Tests after Conditioning			
	No.	Cycle Days	Peak	Avg.	Rifle Engraving	Falling Dart	Temp °F	Muzzle Velocity, fps Range	Muzzle Velocity, fps Avg.	Observations from Microflash Photographs
119603-102C (continued)	-331	28	16	14			-65	3862-3943	3899	4 units; 1 flaking, others satisfactory.
							160	3884-3943	3904	4 units; all intact but wearing.
	-810	28			Pass	Pass	-65	3914-3951	3936	3 units; all satisfactory.
							160	3906-3928	3916	3 units; all intact but wearing.

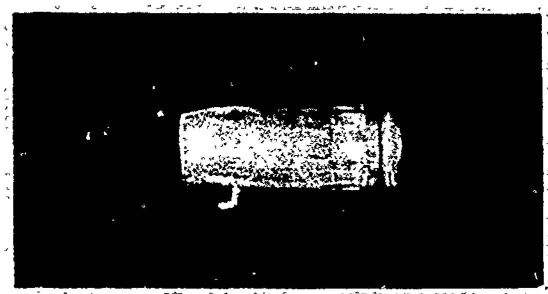


3,884 Feet per Second at -65°F



3,884 Feet per Second at 160°F

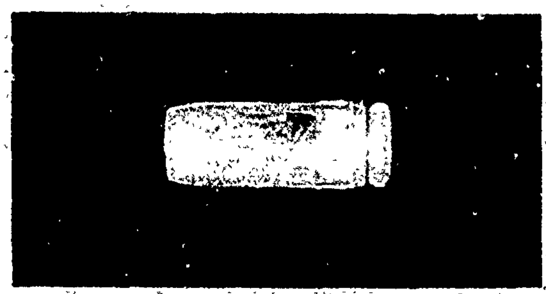
MIL-STD-331, Test 105, 28 Days



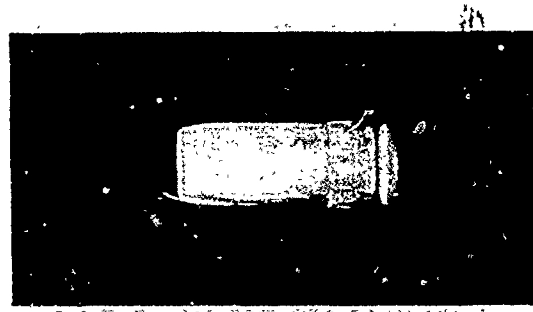
3,848 Feet per Second at -65°F

3,906 Feet per Second at 160°F

MIL-STD-331, Test 105, 14 Days



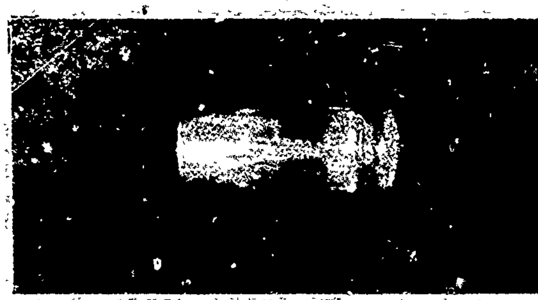
3,899 Feet per Second at -65°F



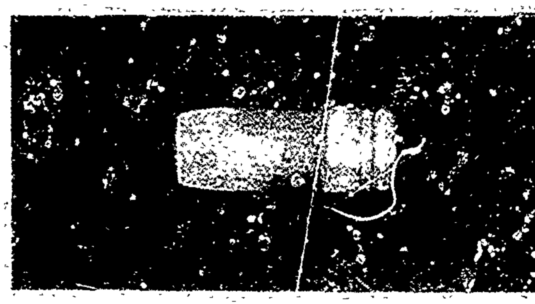
3,921 Feet per Second at 160°F

MIL-STD-810B, Method 507, Procedure IV, 28 Days

Figure 47. Firing Trials on Uncoated and Sub-Gated Nylon 12 Rotating Bands after Temperature and Humidity Cycling in Accordance with MIL-STD-331 and MIL-STD-810B, Projectile Series 117625-87

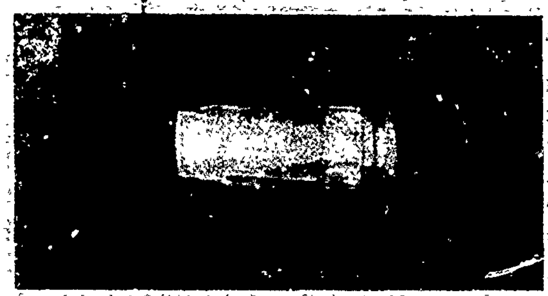


3,914 Feet per Second at -65°F

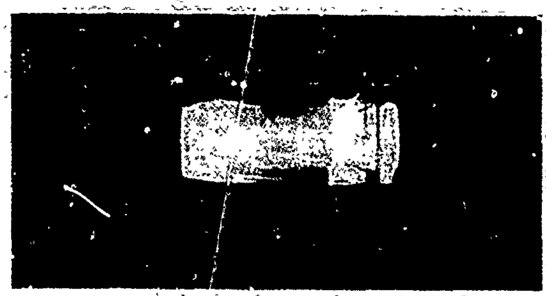


3,899 Feet per Second at 160°F

MIL-STD-331, Test 105, 28 Days

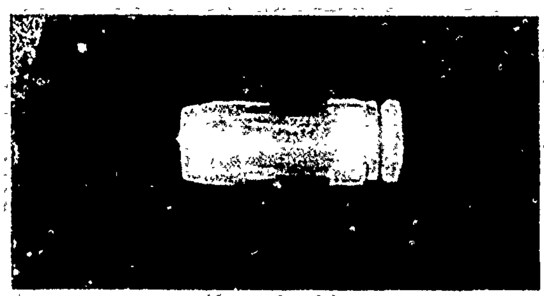


3,884 Feet per Second at -65°F

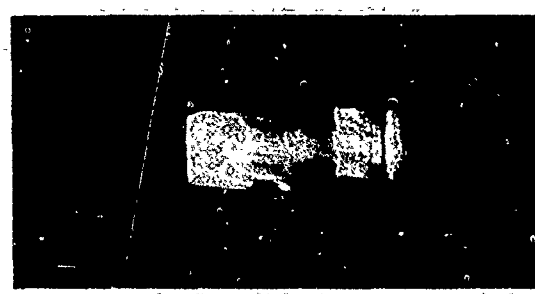


3,943 Feet per Second at 160°F

MIL-STD-331, Test 105, 14 Days



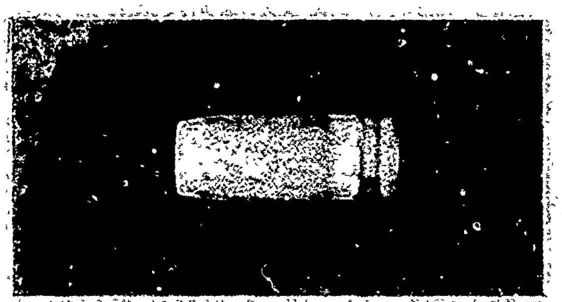
3,914 Feet per Second at -65°F



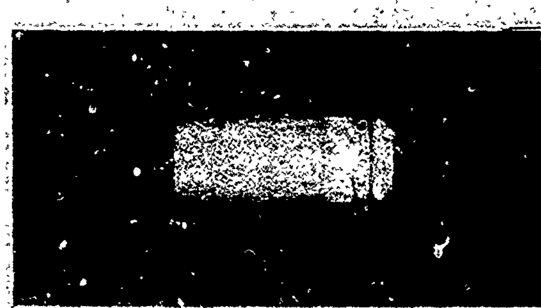
3,921 Feet per Second at 160°F

MIL-STD-810B, Method 507, Procedure IV, 28 Days

Figure 48. Firing Trials on Urethane Varnish Coated and Sub-Gated Nylon 12 Rotating Bands after Temperature and Humidity Cycling in Accordance with MIL-STD-331 and MIL-STD-810B, Projectile Series 117625-87C

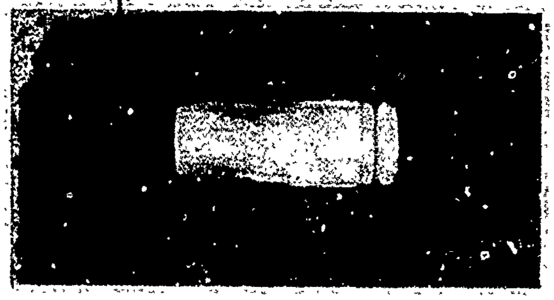


3,848 Feet per Second at -65°F

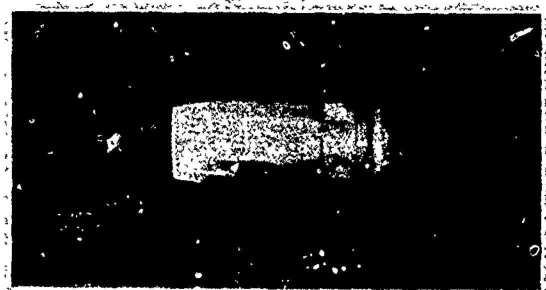


3,855 Feet per Second at 160°F

MIL-STD-331, Test 105, 28 Days

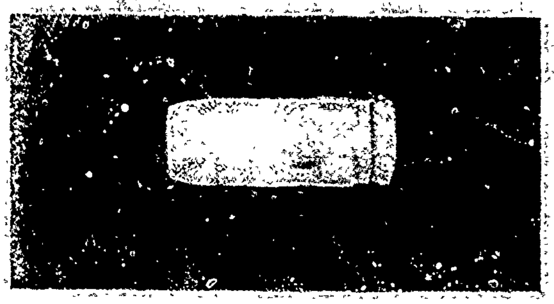


3,848 Feet per Second at -65°F

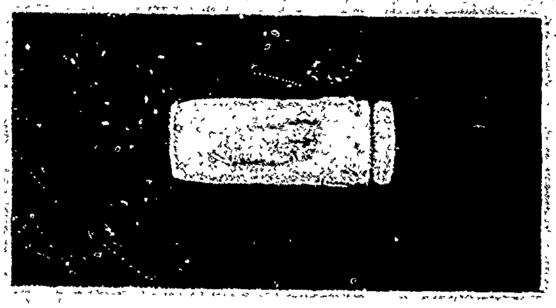


3,862 Feet per Second at 160°F

MIL-STD-331, Test 105, 14 Days



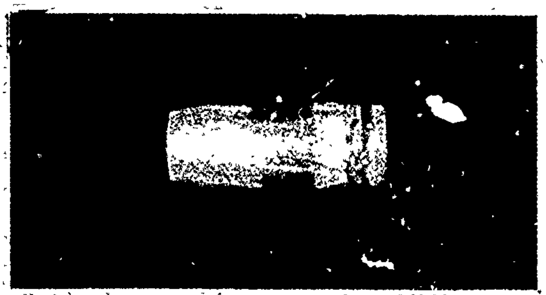
3,914 Feet per Second at -65°F



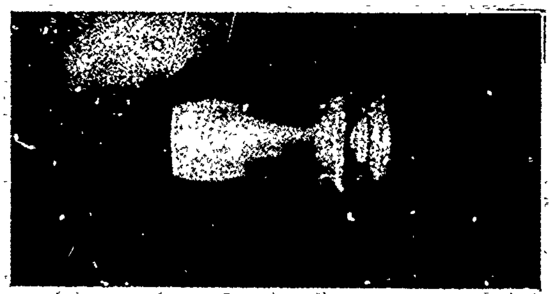
3,936 Feet per Second at 160°F

MIL-STD-810B, Method 507, Procedure IV, 28 Days

Figure 49. Firing Trials on Uncoated and Ring Gated Nylon 12 Rotating Bands after Temperature and Humidity Cycling in Accordance with MIL-STD-331 and MIL-STD-810B, Projectile Series 119603-101

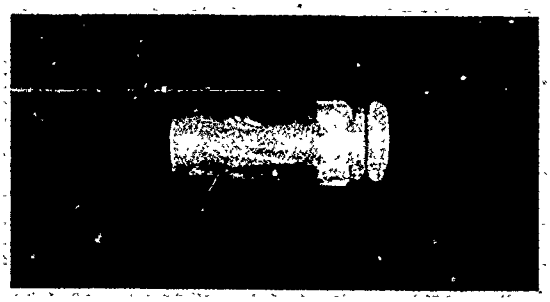


3,899 Feet per Second at -65°F



3,884 Feet per Second at 160°F

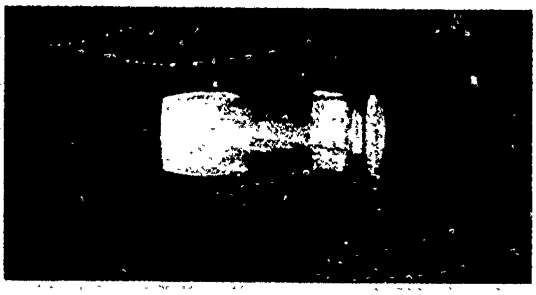
MIL-STD-331, Test 105, 28 Days



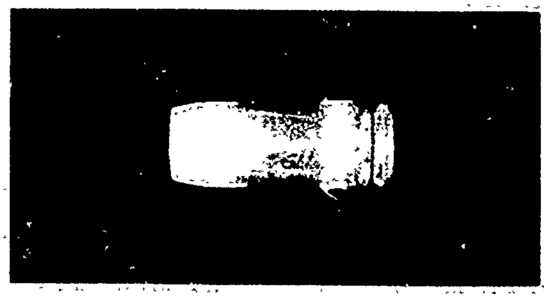
3,877 Feet per Second at -65°F

3,884 Feet per Second at 160°F

MIL-STD-331, Test 105, 14 Days



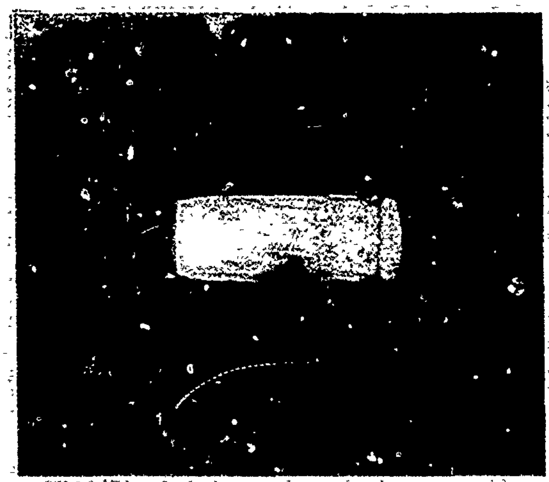
3,936 Feet per Second at -65°F



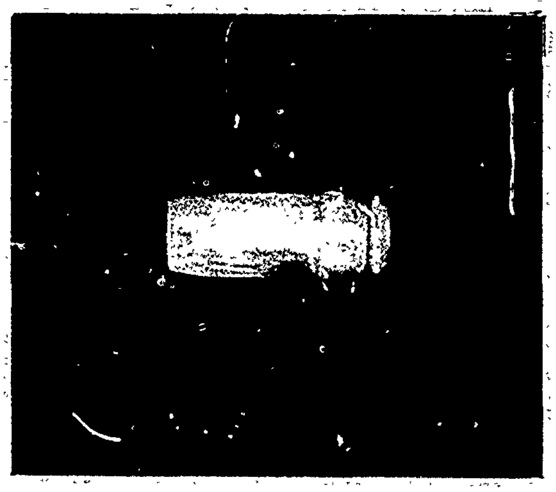
3,906 Feet per Second at 160°F

MIL-STD-810B, Method 507, Procedure IV, 28 Days

Figure 50. Firing Trials on Epoxy Coated and Ring Gated Nylon 12 Rotating Bands after Temperature and Humidity Cycling in Accordance with MIL-STD-331 and MIL-STD-810B, Projectile Series 119603-101C

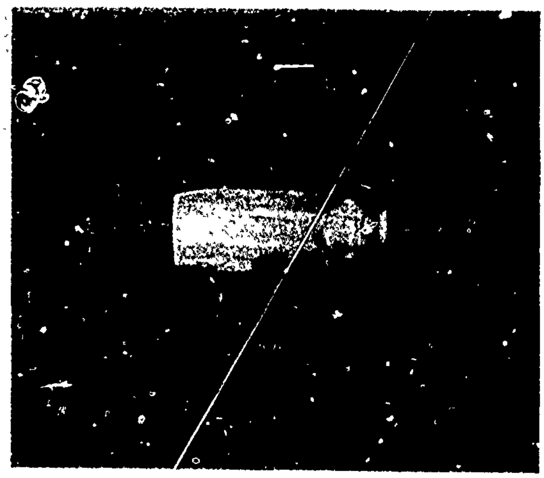


3,884 Feet per Second at -65°F

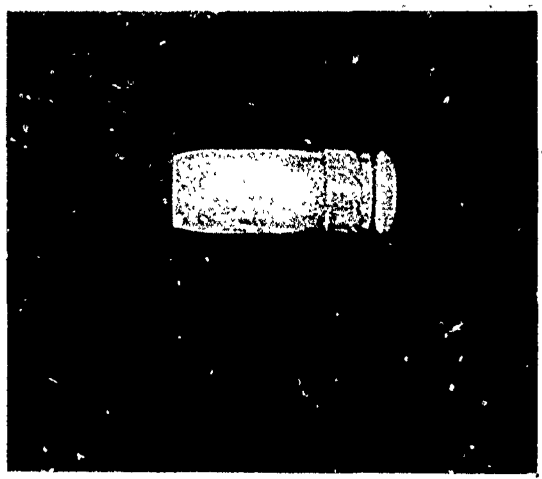


3,982 Feet per Second at 160°F

MIL-STD-331, Test 105, 28 Days



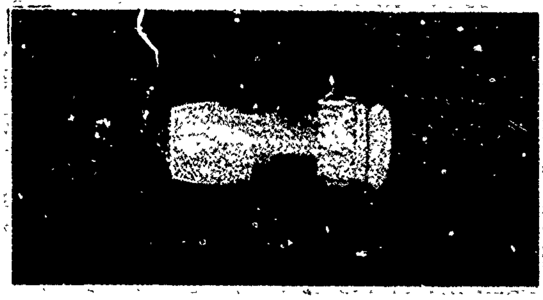
3,89[illegible] Feet per Second at -65°F



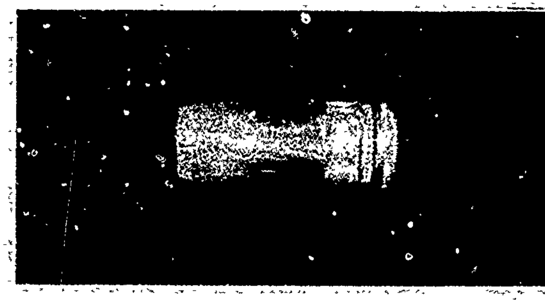
3,355 Feet per Second at 160°F

MIL-STD-331, Test 105, [illegible] Days

Figure 51. Firing Trials on Uncoated and Sub-Gated Nylon 12 Rotating Bands after Temperature and Humidity Cycling in Accordance with MIL-STD-331, Projectile Series 119603-102

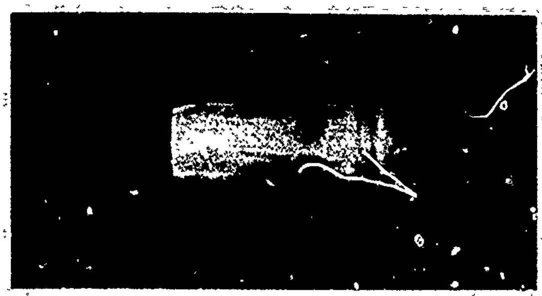


3,943 Feet per Second at -65°F

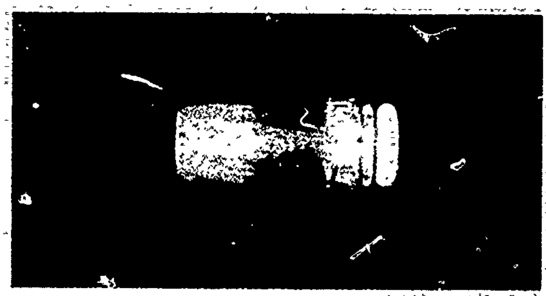


3,906 Feet per Second at 160°F

MIL-STD-331, Test 105, 28 Days

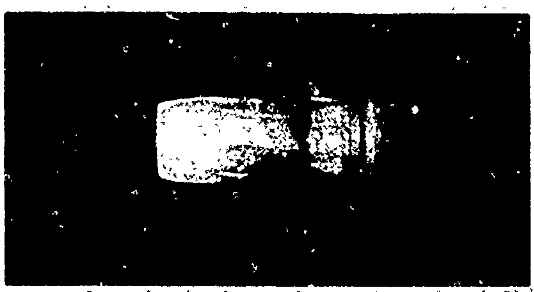


3,884 Feet per Second at -65°F

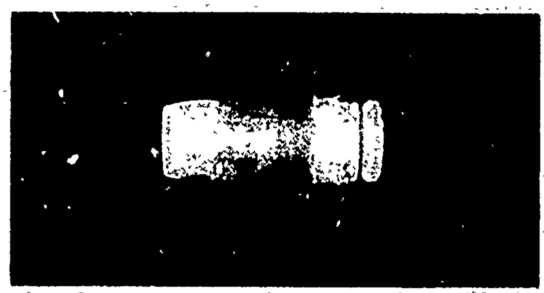


3,891 Feet per Second at 160°F

MIL-STD-331, Test 105, 14 Days



3,951 Feet per Second at -65°F



3,914 Feet per Second at 160°F

MIL-STD-810B, Method 507, Procedure IV, 28 Days

Figure 52. Firing Trials on Epoxy Coated and Sub-Gated Nylon 12 Rotating Bands after Temperature and Humidity Cycling in Accordance with MIL-STD-331 and MIL-STD-810B, Projectile Series 119603-102C

SECTION III

MANUFACTURING

Based on the results of the development phase of the program, authorization to proceed with the production phase was granted by the sponsor. Included in this activity were the design and development of tooling and equipment which would simulate that necessary for mass production, as well as the production of 39,600 units. These activities are described in this report.

TOOLING AND EQUIPMENT

The special tooling and equipment used in the program consisted of racks and mandrels for priming and baking, a four-cavity injection mold, and a feed system for induction bonding. Each is described in this section.

Priming Racks and Mandrels. During the development phase of the program, projectiles were individually hand-held during dip priming, positioned on baking trays, and, after baking, carefully removed from the oven to prevent toppling the relatively unstable base positioned projectiles. Toppling of one projectile would lead to a domino-type succession of toppling of the other projectiles, with an end result of contamination of the primed surface. Recognizing that this would be a rather cumbersome method for mass production, a system of racks and mandrels was developed which would permit priming large quantities of projectiles expeditiously as well as stable mounting for handling during and after the baking process. The equipment includes long bars affixed with threaded mandrels upon which projectiles could be threaded at their fuze ends. These mounted projectiles could then be gang dipped, and the mounted gangs of projectiles could be stored upon the special oven racks for drying, baking, and cooling without fear of toppling. Three sets of equipment were employed in the program in order to permit no lost time during the priming and baking cycles.

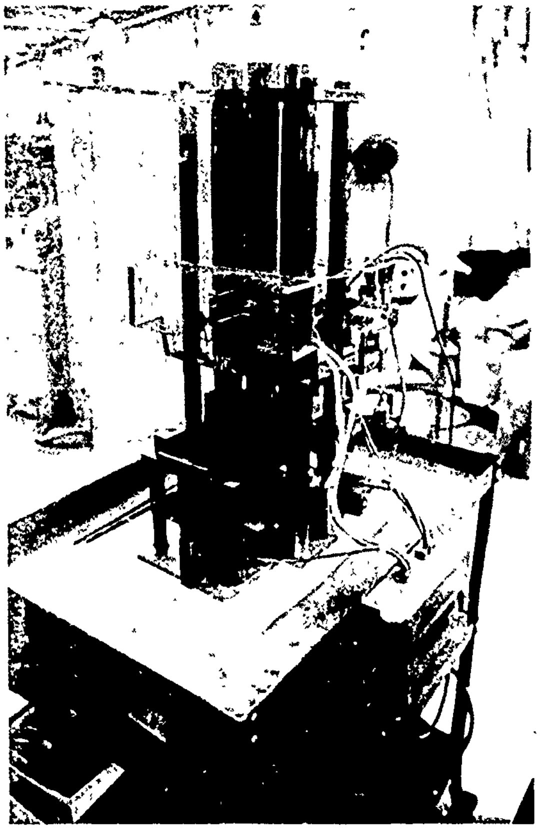
Projectile Preheater. An established fact determined from the development phase was that the projectiles must be preheated prior to molding. During that phase, preheating was accomplished by placing trays of base positioned primed projectiles within a hot air oven. The molding operator would open the oven door and carefully withdraw (to prevent toppling the load of projectiles) units to be molded, close the oven door, and insert the heated projectiles into the injection mold. During this procedure, cool air was introduced into the oven each time the door was opened, which resulted in erratic temperatures of the projectiles. The temperature variation was increased each time a new tray batch of projectiles was introduced into the preheating oven. Since this type of process variation could not be tolerated in production, a preheating device was developed which would permit uniform preheating of the projectiles, stable handling, and automatic dispensing of heated projectiles.

The projectile preheater consists of heated storage tubes which feed a heated shuttle out-feeder. Projectiles are manually loaded into the top of the electrically heated storage tubes, and they are heated by conduction during their residence in the tubes prior to out-feed on the steam-heated shuttle. The tubes hold a stack of ten projectiles each, with a total residence of approximately 10 minutes each (ten molding cycles). The projectiles advance down the tubes by gravity until they arrive at the pneumatically operated and electrically sequenced shuttle block. Depressing an electric foot switch causes a pneumatic piston to slide the shuttle block with its load of projectiles into position over an ejector system, and the ejector system, in automatic sequence with the foot switch, raises the projectiles from the shuttle block and presents them, uniformly heated, to the molding operator for insertion in the injection mold. Figure 53 shows the equipment both in residence (closed) condition and with the shuttle block and ejector system operated.

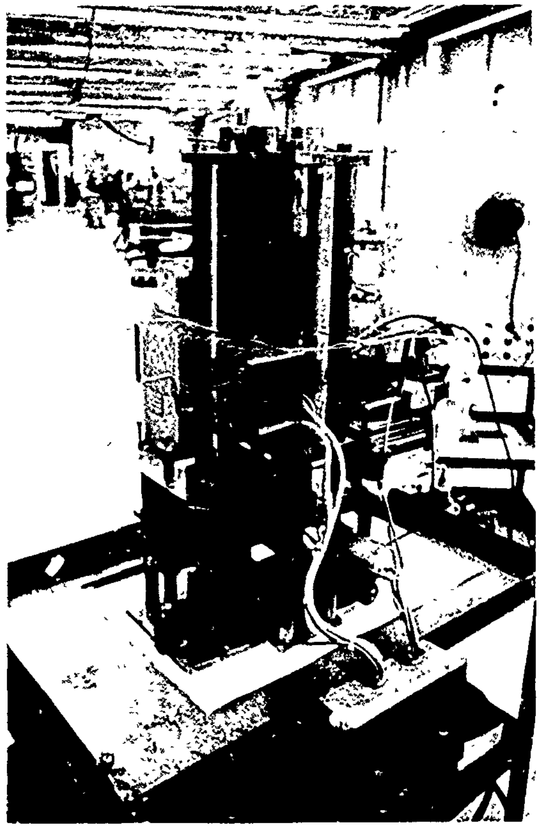
With slight modification, this system is adaptable to an automatic, shuttle plate, molding operation. In this case, after demolding the finished projectiles, the mold shuttle plate of a vertically positioned injection mold would advance under the preheater system, actuate a gate mechanism, and receive by gravity the next load of projectiles for molding. The shuttle plate would then return to the molding position within the press, all of which could be done on an automatic cycle.

Injection Mold. During the development phase, a two-plate, two-cavity, injection mold was used in conjunction with cavity inserts which, by choice for such activity, produced oversize rotating bands which were machine finished to their required dimensions. The machine finishing operation was obviously not desired for a production process, and it was proven during the development that bands finished to size before induction bonding, provided that the cycle was fast enough, could be bonded without distortion to either the edge tapers or the diameter, and that they would perform satisfactorily in gun fire tests. The production mold, therefore, was designed with cavity dimensions which would produce rotating bands with the desired finished dimensions.

The production mold contained four cavities and utilized a cold runner system in a two-plate configuration. The cavities were sub-gated to permit automatic runner release from the molded rotating bands during the mold opening sequence. The parting line of the cavity plate was established at the junction of the band aft taper and the outer diameter. An ejector system automatically demolded the banded projectiles and runner



Closed Position



Shuttle and Ejector Actuated

Figure 53. Projectile Preheater in Operation

during mold opening. The mold was designed for use in a horizontal clamp press, and steam channels were provided within the mold frame for proper temperature control. The cavities were hardened to prevent wear and galling.

Induction Bonding Feed System. During the development phase of the program, induction bonding of the projectiles was accomplished in the same manner as described in AFATL-TR-74-106, i.e., manual positioning of the projectiles in the center of a work coil with the projectile resting on its base on an asbestos plate, manual activation of the radio frequency generator's timed power cycle, manual removal from the coil followed by a plunge into a water quench bath, and manual recovery from the bath and drying of each projectile to prevent corrosion. This type of operation could not be tolerated in a high volume production process. Therefore, an automatic in-and-out feed system was developed for coupling with the radio frequency generator and which would mechanically perform all of the manual operations.

Figure 54 depicts the system. Projectiles are manually placed in a vibrating track which advances them to a magnetic pick-off on a swing arm. The arm advances a projectile in position over the bonding coil of a 5KW radio frequency generator, while the back side of the arm, being a circular arc, acts as a gate for the other projectiles on the vibratory track. A vacuum pick-off plunger slides the projectile from the magnetic holder of the swing arm, positions it in the center of the induction coil at the proper elevation, and starts a time delay sequence. After a half second, the time delay circuit starts the induction heating cycle on the radio frequency generator, while the swing arm returns to pick off another projectile for processing. After the bonding interval set by the timer of the generator the heating cycle automatically stops, and after a half second delay, a switching valve reverses the vacuum of the holding plunger to a pneumatic blow-off. The projectile is blown from the plunger into a quench bath of cool water, where a ladder conveyor delivers it to a driving conveyor. Dried projectiles are collected manually and packaged.

PRODUCTION

Using the materials and processes specified in Appendix A and with the above tooling and equipment, 39,600 projectiles were manufactured with nylon 12 rotating bands. M56A4 projectile bodies were furnished by the sponsor complete with band seats and zinc phosphating in accordance with applicable drawings and specifications. The production phase was separated into three distinct activities, each of which is described herein.

Preparation. The preparation activity consisted of gaging, cleaning, priming, and baking. Because of observed discrepancies on the projectile surfaces (burrs and oversize conditions) which were potentially damaging to the injection mold cavities, each received projectile was go-ring gaged, with approximately one in 5,000 units rejected for such discrepancies. The gaged projectiles were then washed in methyl ethyl ketone and threadedly attached to the priming mandrels. The projectiles were gang dipped in M&T 253-P primer diluted to 23 centipoise with M&T 200-T thinner, and the excess primer solution was removed by shaking. The gangs of primed projectiles were positioned on oven racks to evaporate the excess solvent, after which the batch of projectiles was placed in a hot air tunnel oven maintained at 450°F, for a 40-minute period. The gangs of projectiles were removed from the oven and placed on cooling racks, and the oven racks were recycled. After forced air (fan) cooling, the prepared projectiles were stripped from the mandrels and packaged for molding, and

In-Feed and Bonding Station   Out-Feed and Drying Conveyor

Figure 54. Induction Bonding In-and-Out Feed Equipment

the mandrels were recycled. One operator performed all of the activities at an average output of 160 projectiles per hour. Figures 55, 56, and 57 depict some of the activities.

Molding. In preparation for the molding activity, the nylon 12 molding material was dried in a circulating oven for 12 hours at 175°F, and primed projectiles were removed from stores on a first-in, first-out basis. Mold and press parameters were established in accordance with the applicable process specification, and the projectiles were loaded into the preheater. Preheated projectiles were loaded, base first, into the four-cavity mold, and the mold cycle was consummated by automatic press sequencing at an average rate of 200 projectiles per hour.

After demolding, the projectiles were examined for defects, including excessive flash at the bourrelet and parting line, contamination, mold drag, and band seat voids. The latter was deemed to be a major defect proven to

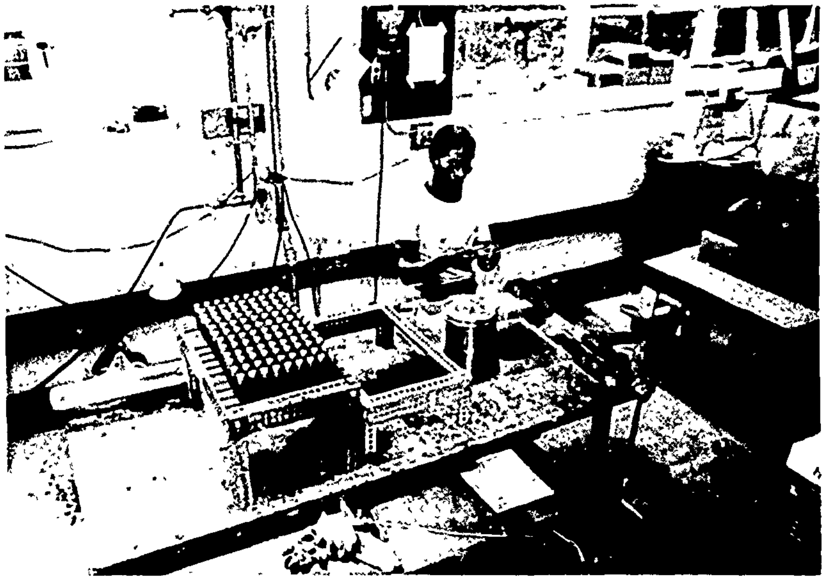


Figure 55. Gaging and Cleaning

cause band failure in firing, even though the defect could often be apparently corrected by the bonding process, and it resulted in rejection of the molded unit. After start-up variables settled out, however, this type of reject was rare. Bourrelet flash, a condition caused by undersize projectile diameters or by damage at the case neck stop, occurred randomly at a relatively high frequency throughout the molding activity. The corrective action to minimize this problem was to reduce the molding pressures to slightly less than the optimum desired maximum levels. However, the reduced pressure was within the limits established in process specification DRPS 6046.3.4, a copy of which is included herein. Excessive parting line flash was prevalent in the first 1,000 units, but corrective action requiring some minor mold rework alleviated the defect.

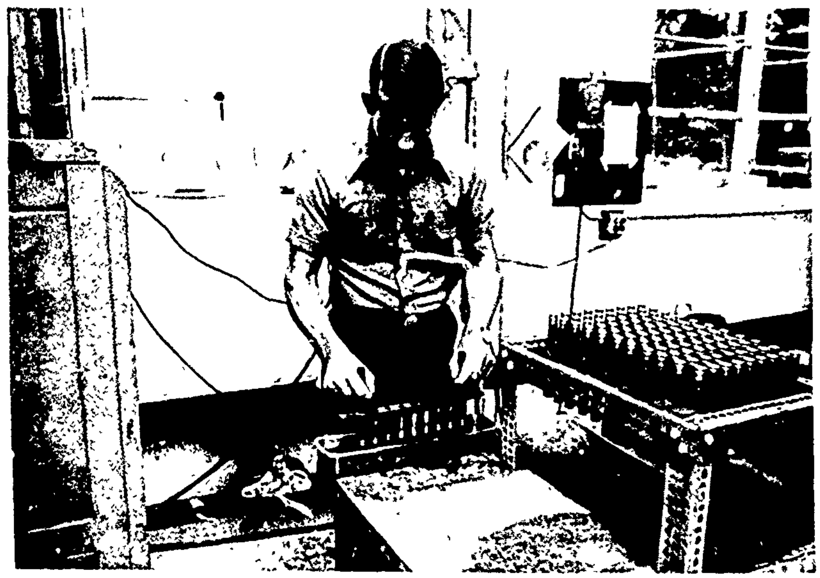


Figure 56. Gang Dip Priming

Figure 57. Primed and Baked Projectiles Set Aside for Cooling

Induction Bonding. Molded projectiles were stored for a 4 to 24-hour period prior to induction bonding in order that the units be uniformly cool and that all plastic morphological changes have taken place. The equipment was set up as described in process specification DRPS 6046.3.5, for a 4-1/4-second heating cycle. As each projectile loaded on the vibratory in-feed track of the equipment, it was again inspected for molding and any other defects, with the most important defect being voids which may have developed at the band seat as a result of any morphological changes. Units containing such defects were rejected, but the frequency of this defect was less than 1 per thousand units. The bonding process, using projectiles molded in sequence, was consummated automatically as previously described in the tooling section. It was performed at an average of 550 projectiles per hour. One of every hundred bonded units was subjected to the 60 foot-pound falling dart test after removal from the quench bath, with the requirement that no debonding or fracture occur outside of the impact zone. Rejection of a projectile for these effects required additional destructive testing of 1 of 10 units sequentially before and after the original failure in order to determine the zone of rejection. Projectiles residing between the last test successes were rejected. This inspection procedure isolated and rejected approximately 200 projectiles from the production batch. Accepted units were sent to the sponsor or his designate (Lake City Ammunition Plant, Independence, Missouri) for final disposition.

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

A data package for the production of highly reliable nylon 12 plastic rotating bands for M56A4 20mm projectiles has been developed. The package includes band seat geometry, materials, processing, band geometry, and tooling requirements that result in successful performance. The parameters determined were verified in a development program which thoroughly studied each detail prior to incorporation in the data package, and the utility of the information was tested in a large volume manufacturing program. The processing used in this pilot manufacturing activity is considered to be readily adaptable to multi-million per annum production of bonded plastic rotating bands.

The pilot production program also showed the need for improved quality of the steel projectile bodies. The present combination of diameter tolerances and concentricity between the fore and aft sections of the projectiles requires that the mating areas of the rotating band mold cavities be compensated in order to be able to receive all the variations of the projectile dimensions. This ultimately leads to undesired flash of the melted plastic during the injection cycle. In addition, damage to the case neck stop or localized undersize conditions adjacent to the band seat groove similarly lead to excessive molding flash. Tighter manufacturing control of the projectile bodies should minimize this problem.

The program also showed that considerable doubt existed over the worth of temperature and humidity cycling in accordance with MIL-STD-331, Test 105. This particular test method was developed about the pre-failure point of mercury fulminate detonators in fuze applications. When the use of mercury fulminate was all but discontinued, the specification was retained, but with the statement: "The 14-day cycle was chosen as the basic unit because this period is a little shorter than that required to cause failure of mercury fulminate detonators which are still present in existing fuzes. It was recognized, however, that future designs should not contain fulminate and thus should stand this more severe test or a minimum of two (2) Temperature and Humidity cycles (28 days)." It is recommended that this test procedure be abandoned in favor of another which would more realistically assess the life storage conditions of projectiles having bonded plastic rotating bands.

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APPENDIX A

MATERIALS AND PROCESS SPECIFICATIONS

MATERIAL SPECIFICATION DRMS 6046.3.1

EPOXY ADHESIVE/PRIMER FOR BONDING PLASTIC ROTATING BANDS TO PROJECTILES

1. SCOPE

This is a material specification for an epoxy adhesive/primer for use in bonding plastic rotating bands to metal projectiles.

2. REFERENCE DOCUMENTS

The following DeBell & Richardson specifications form a part of this specification to the extent intended herein:

DRPS 6046.3.4	Molding Nylon 12 Rotating Bands for Induction Bonding to Projectiles
DRPS 6046.3.5	Induction Bonding Nylon 12 Plastic Rotating Bands onto 20mm M56A4 Projectiles
DRTP 6065.2.1	Laboratory Test Methods for the Evaluation of Plastic Materials for Projectile Rotating Bands

3. REQUIREMENTS

3.1. General

3.1.1. The adhesive/primer shall be a liquidous thermosetting epoxy resin system suitable for dip, brush, or spray coating metallic surfaces.

3.1.2. The material, when cured, shall adhere firmly to bare steel, zinc phosphated steel, aluminum, and anodized aluminum surfaces.

3.1.3. The cured adhesive/primer shall have an affinity for bonding nylons 11, 12, and 612, most polyamides, thermoplastic ether polyurethanes, thermoplastic ester urethanes, and thermoplastic polyesters through heat and/or induction (radio frequency) bonding.

3.1.4. The cured adhesive/primer shall provide a suitable corrosion barrier to bare and zinc phosphated steel when they are subjected to salt spray and humidity environments.

3.1.5. The adhesive/primer shall be dilutable by ketones or ketone blends for facilitating dip or spray coating.

3.2. Physical Properties

3.2.1. Liquid State

3.2.1.1. Undiluted adhesive/primer shall have the following characteristics:

Viscosity:	25-27 seconds, #4 Ford cup
Total Solids:	32-34 percent
Weight:	7.9 - 8.1 lb/gallon
Flash Point:	58^{o}F (closed Tag cup)

3.2.1.2. When diluted 1:1 by volume with methyl ethyl ketone or approved solvent (see paragraph 5.2), the viscosity shall be 20-25 centipoise.

3.2.1.3. The material shall exhibit an infrared transmittance spectrum as shown in Figure 1.

3.2.1.4. The material shall be amber colored in bulk volume, and applied coatings therefrom shall be water clear.

3.2.1.5. The shelf life shall be two years when stored in sealed metal containers at 70°F.

3.2.2. Cured State

3.2.2.1. The cured coating shall be resistant to ketones.

3.2.2.2. The ring shear strength of the adhesive/primer, when properly processed with nylons 11 and 12, shall exceed 4000 psi (Ref: DeBell & Richardson test procedure DRTP 6065.2.1, paragraph 3.1).

4. ACCEPTANCE CRITERIA

The criteria specified herein shall be used to verify the quality of each batch of adhesive/primer.

4.1. The material shall be diluted 1:1 by volume with methyl ethyl ketone or with approved solvent (see paragraph 5.2), and the viscosity shall be 20-25 centipoise.

4.2. A sample of material shall be scanned by infrared spectroscopy, and the transmittance shall be generally as indicated in Figure 1.

4.3. Test projectiles, manufactured in accordance with process specifications DRPS 6046.3.4. (with DRPS 6046.3.5), shall be subjected to the impact engraving and falling dart tests of DeBell & Richardson procedure DRTP 6065.2.1, paragraphs 3.4 and 3.5. There shall be no failures.

4.4. Ring shear test bars, using the methods and materials of the process specifications cited in paragraph 4.3, above, shall be subjected to the testing of paragraph 3.1 of DeBell & Richardson test procedure DRTP 6065.2.1. The shear strength shall exceed 4000 psi for the nylon 12 material. Failure to meet these levels shall result in rejection of the primer/adhesive.

5. QUALIFIED PRODUCTS LISTING

The following products have been qualified as acceptable to the conditions of this specification:

5.1. Primer/Adhesives

253-P M&T Chemicals, Inc., Rahway, New Jersey

5.2. Thinners

200-T M&T Chemicals, Inc., Rahway, New Jersey

MATERIAL SPECIFICATION DRMS 6046.3.2

NYLON 12 FOR BONDED
ROTATING BANDS ON 20MM PROJECTILES

1. SCOPE

This is a material specification for a thermoplastic, injection moldable, nylon 12 for molding and bonding to 20mm projectiles.

2. REFERENCE DOCUMENTS

The following documents form a part of this specification to the extent intended herein:

2.1. Military Specifications

MIL-STD-810	Environmental Test Methods

2.2. DeBell & Richardson Specifications

DRPS 6046.3.3	Preparation of Projectiles for Molding and Bonding Thermoplastic Rotating Bands
DRPS 6046.3.4	Molding Nylon 12 Rotating Bands for Induction Bonding to Projectiles
DRPS 6046.3.5	Induction Bonding Nylon 12 Plastic Rotating Bands onto 20mm Projectiles
DRTP 6065.2.1	Laboratory Test Methods for the Evaluation of Plastic Materials for Projectile Rotating Bands

3. REQUIREMENTS

3.1. General

3.1.1. The material shall be an injection moldable grade of nylon 12.

3.1.2. The material shall be capable of being injection molded in accordance with DeBell & Richardson specification DRPS 6046.3.4 directly onto steel projectiles which have been zinc phosphated and primed in accordance with DeBell & Richardson specification DRPS 6046.3.3, after which induction bonding methods in accordance with DeBell & Richardson specification DRPS 6046.3.5 shall provide an intimate bond with the projectiles.

3.1.3. The material, when properly processed as a rotating band on 20mm projectiles, shall withstand all firing environments, including muzzle velocities of 4000 feet/second and chamber pressures of 60 kpsi when fired from an M61 gain twist Mann barrel at temperatures from -65° to 160°F, with a band length of 0.280 inch. In addition, the material shall withstand these same firing environments after 28-day temperature and humidity conditioning in accordance with MIL-STD-810B, Method 507, Procedure IV. There shall be no band discard, chunking, or excess fringing and fraying.

3.1.4. The material shall be suitable for use on projectiles with band seats.

3.2. Physical Properties

The material shall exhibit the following dry, as molded, physical properties at 70°F:

Property	Test Method	Value
Tensile Yield strength, psi	ASTM D638	5,500
Tensile Break strength, psi	ASTM D638	5,600
Elongation at yield, percent	ASTM D638	20
Elongation at break, percent	ASTM D638	470
Tensile modulus, psi	ASTM D638	180,000
Compressive Strength, psi	ASTM D695	7,000
Flexural strength, psi	ASTM D790	9,800
Flexural modulus, psi	ASTM D790	245,000
Impact strength: 1/2 x 1/8 sample, Izod, notched, ft-lb/inch of notch	ASTM D256	1.2

Property	Test Method	Value
Hardness, Rockwell "M"	ASTM D785	39
Gardner Impact, ft-lb/mil		0.33
Mold Shrinkage, percent		1.6
Density	ASTM D792	1.01

4. ACCEPTANCE CRITERIA

4.1. The materials shall meet the requirements of paragraph 3.2, above.

4.2. The ring shear bond strength to bare steel test bars prepared in accordance with DeBell & Richardson specification DRPS 6046.3.3, DRPS 6046.3.4, and DRPS 6046.3.5 shall exceed 4000 psi when tested in accordance with DeBell & Richardson specification DRTP 6065.2.1, paragraph 3.1.

4.3. 20mm projectiles, upon which rotating bands of the material have been processed in accordance with DeBell & Richardson specifications DRPS 6046.3.3, DRPS 6046.3.4. and DRPS 6046.3.5, shall be subjected to the impact engraving and falling dart tests of DeBell & Richardson specification DRTP 6065.2.1, paragraphs 3.4 and 3.5, without failure.

5. QUALIFIED PRODUCTS LISTING

The following products have been qualified to this specification:

Product No.	Manufacturer
Vestamide L1801	Huls

PROCESS SPECIFICATION DRPS 6046.3.3

PREPARATION OF PROJECTILES FOR MOLDING AND BONDING THERMOPLASTIC ROTATING BANDS

1. SCOPE

This is a process specification for the preparation of metal projectiles for which thermoplastic rotating bands are to be molded and bonded thereto. Included herein are the metal surface finish requirements, cleaning of the metal surface, priming, and primer cure.

2. REFERENCE DOCUMENTS

The following documents form a part of this specification to the extent intended herein:

2.1. Federal Specifications

TT-C-490B	Cleaning Methods and Pretreatment of Ferrous Surfaces for Organic Coatings

2.2. DeBell & Richardson Specifications

DRMS 6046.3.1	Epoxy Adhesive/Primer for Bonding Plastic Rotating Bands to Projectiles

3. REQUIRED EQUIPMENT AND SUPPLIES

The following equipment and supplies will be necessary for preparing projectiles to receive molded and bonded rotating bands:

a. Cleaning tanks

b. Toluene and methyl ethyl ketone solvents

c. Primer materials in accordance with DeBell & Richardson Specification DRMS 6046. 3. 1

d. Priming racks

e. Curing oven

f. Viscosimeter

g. Dipping troughs or spraying equipment

h. Temperature recorder and thermocouples.

4. PROCEDURES

The following procedures shall be followed for preparing projectiles to receive molded and bonded rotating bands.

4. 1. Band Seat Surface

The dimensions of the band seat, its material, and protective coating (if any) are controlled by the applicable engineering drawing. However, each is important to the effectiveness of the primer coating. The following shall be verified:

4. 1. 1. Roughness

The seats shall be free of burrs and sharp edges. Sharp edges at the junction of the seat with the projectile bourrelet may cause mold damage as well as permit the primer coat to be bridged or pierced. In addition, the surface finish shall be between 40 and 80 rms microinches; too smooth finish results in weak bonding of the prin r to the substrate, and too coarse of a surface promotes localized primer bridging.

4.1.2. Surface Coating

Steel surfaces shall be zinc-phosphated in accordance with Federal Specification TT-C-490B at the minimum weight, fine grain, and dust free. Dusting indicates poor phosphate adhesion to the metal substrate, and it will result in weak bonds. Aluminum substrates may be plain or anodized.

4.2. Cleaning

Band seats, regardless of their material or surface coating, shall be cleaned prior to priming, and the methods shall be as described herein. Many methods and materials are available for cleaning, and they include hot vapor degreasing, solvent washing, alkaline cleaning, etc. Many of the methods are adaptable to volume production processes, and some are incompatible with the overall process. For example, processes using aqueous chemicals should be avoided in conjunction with zinc phosphated steel projectiles. An accepted procedure is as follows:

a. In an immersion bath of toluene aromatic solvent, scrub or agitate the projectiles until all traces of surface contamination are removed.

b. Following the toluene bath, rinse the projectiles in methyl ethyl ketone solvent and set them aside in a clean area to air dry. The rinse bath shall be filtered or changed regularly.

4.3. Priming

The primer, as specified in DeBell & Richardson Specification DRMS 6046.3.1, can be applied by brush, dip, or spray. Except for limited developmental cases, brush coating is not acceptable, whereas dipping and spraying are both economical and acceptable. Either of these can be accomplished manually or in automation. An accepted dip priming process is as follows:

a. Mix the primer and diluent at a volume ratio of 1:1. Verify that the viscosity is between 20 and 25 centipoise. Allow entrapped air to escape before using. Note: mixed primer can be stored covered for extended periods. However, solvent evaporation can cause a viscosity increase. If this occurs, blend in additional diluent until the viscosity range is as prescribed above.

b. Pour a quantity of mixed primer into the dipping trough at a level such that the band seats of the immersed projectiles would be at least 1/4 inch below the level of the liquid.

c. Mount the projectiles on the priming racks, being careful not to handle the band seat area.

d. Dip the racked projectiles into the primer and hold for a few seconds to rid the band seat area of any entrapped air.

e. Remove the racked projectiles from the primer bath and drain the major excess for a few seconds. Immediately and vigorously shake off the excess primer.

f. Set the racked units aside for 15 minutes to air dry. While drying, examine the units for signs of runs or drip marks. Reject those that contain such defects.

4.4. <u>Curing</u>

The primer must be oven cured. Curing schedules are varied and are dependent on the batch size and oven capacity. The differential temperature within the oven chamber shall be as uniform as possible in order that the batch of projectiles cure to the same degree. The primer will show no appreciable color change with insufficient curing, while excessive overcuring will result in blackened coatings. A satisfactory cure is when the primer is a golden amber color. A satisfactory cure procedure is as follows:

a. Place a thermocoupled projectile blank in with the racks of primed projectiles.

b. Set and maintain the oven temperature at 450°F.

c. Place the racked projectiles into the preheated oven. When the surface temperature of the thermocoupled projectile reaches 425°F, allow an additional 15 minutes of cure time. A typical time-temperature cycle would be about 35 minutes at 450°F.

d. Remove the racked projectiles from the oven and allow them to cool in air in a clean area.

4.5. Inspection and Storage

a. After the projectiles have cooled to less than 120°F, strip them from the priming racks.

b. Inspect the coating for the proper color (see subsection 4.4). Undercured units can be recycled into the oven, but overcured projectiles shall be rejected.

c. The cured coating will be resistant to ketone attack and softening. On a representative sample from each oven batch, rub an area outside of the band seat with a coarse cloth moistened with methyl ethyl ketone. There shall be no evidence of coating removal.

d. The projectiles may be stored for long periods in clean, dry, covered boxes. Avoid any handling of the band seat area.

PROCESS SPECIFICATION DRPS 6046.3.4

MOLDING NYLON 12 ROTATING BANDS FOR INDUCTION BONDING TO PROJECTILES

1. SCOPE

This is a process specification for molding nylon 12 plastic onto primed 20mm projectiles which will ultimately be induction bonded.

2. REFERENCE DOCUMENTS

The following DeBell & Richardson specifications form a part of this specification to the extent intended herein:

DRMS 6046.3.2	Nylon 12 for Bonded Rotating Bands on 20mm Projectiles
DRPS 6046.3.3	Preparation of Projectiles for Molding and Bonding Thermoplastic Rotating Bands

3. REQUIRED EQUIPMENT AND SUPPLIES

The following equipment and supplies will be necessary for molding nylon 12 plastic rotation bands onto projectiles which will ultimately be bonded by induction:

a. Projectile preheating oven or heated loading tubes.

b. Reciprocating screw injection molding press with a non-return valve and nylon tip.

c. Injection mold with suitable cavity dimensions, sub-gated cavities, and heating channels.

d. Mold temperature controllers (or steam network) capable of maintaining a 280°F mold temperature.

e Nylon 12 molding material in accordance with DeBell & Richardson Specification DRMS 6046. 3. 2.

f. 20mm projectiles cleaned and primed in accordance with DeBell & Richardson Specification DRPS 6046. 3. 3.

g. A non-silicone mold release.

h. Material drying oven.

4. PROCEDURES

The following is the setup and operating procedure necessary for molding nylon 12 for bonded projectile rotating bands:

4. 1. Setup

a. Predry the nylon molding material for 12 hours at 175°F in either a vacuum dryer or drying oven using shallow trays.

b. Preheat and maintain the projectile preheat oven or heated loading tubes at 320°F.

c. Establish the mold temperature at 280°F.

d. Establish the following molding press settings:

Front zone heater:	440°F
Mid zone heater:	435°F
Rear zone heater:	410°F
Nozzle heater:	450°F
Injection time:	3 sec
Added hold time:	20 sec
Added mold closed time:	15 sec
Injection pressure:	18 kpsi
Holding pressure:	12 kpsi
Injection speed:	slow
Screw rotation:	moderate
Regrind percentage:	50% maximum

f. Load the primed projectiles into the preheating oven or into the heated loading tubes until the projectile temperature reaches 320°F.

4.2. Molding

After the setup conditions have been established and the conditions equalized, nylon 12 rotating bands shall be molded onto the 20mm projectiles as follows:

a. With the mold open, remove projectiles from the preheating oven or loading tubes and quickly load them into the mold cavities.

b. Quickly close the mold (press gate) and begin the molding cycle automatic sequence.

c. Upon mold opening, open the press gate and demold the banded projectiles (the gate and runner system will automatically shear upon projectile ejection).

d. Set the banded projectiles aside.

e. Repeat the molding cycle for a new batch of projectiles.

4.3. Inspection

After molding, the projectiles shall be visually examined for signs of debonding from the primed substrate. Any debonding, showing up as a whitening or spotting in the band seat, shall be cause for rejection. After inspection, the banded projectiles shall be immediately transported to the induction bonding area. Care shall be taken in handling to avoid disrupting the fragile contact bond between the nylon and the primer.

PROCESS SPECIFICATION DRPS 6046.3.5

INDUCTION BONDING NYLON 12 PLASTIC ROTATING BANDS ONTO 20MM PROJECTILES

1. SCOPE

This is a process specification for induction bonding nylon 12 plastic rotating bands onto 20mm projectiles.

2. REFERENCE DOCUMENTS

The following DeBell & Richardson specifications form a part of this specification to the extent intended herein.

DRPS 6046.3.4	Molding Nylon 12 Rotating Bands for Induction Bonding to Projectiles
DRTP 6065.2.1	Laboratory Test Methods for the Evaluation of Plastic Materials for Projectile Rotating Bands

3. REQUIRED EQUIPMENT AND SUPPLIES

The following equipment and supplies will be necessary for induction bonding nylon 12 banded 20mm projectiles:

a. Radio frequency generator, 5KW capacity minimum.

b. Tubular copper work coil of three turns, 1.30-inch coil ID, and 3/16-inch tube diameter.

c. Water quench bath.

d. Temperature indicating lacquers.

e. In-feed equipment.

f. Out-feed dryer.

g. Impact engraving apparatus.

h. Falling dart apparatus.

i. Unbanded setup projectiles.

j. Projectiles banded in accordance with DeBell & Richardson Specification DRPS 6046.3.4.

4. PROCEDURES

The following procedures shall be used for induction bonding nylon 12 rotating bands to 20mm projectiles:

4.1. Setup

a. Set up the work coil onto the radio frequency generator and start the equipment.

b. Coat some unbanded projectiles with 450° and 500°F indicating lacquers.

c. With the in- and out-feed systems removed from the radio frequency generator, adjust the power and timer settings for a full melt of the indicating lacquers at 450°F and a start of melt at 500°F. The time setting shall be within 4-1/2 seconds. Times in excess of these values will result in excessive band distortion.

d. Using a banded projectile, consummate the bond using the cycle set up above, and quench it in water immediately.

e. After cooling, subject the bonded projectile to the impact engraving and falling dart tests of DeBell & Richardson Specification DRTP 6065.2.1, paragraphs 3.4 and 3.5, at a 60 foot-pound energy level, Any debonding, chunking, fracture, etc., shall be cause for rejection, and it will require an adjustment for bonding cycle.

f. If adjustments in the bonding cycle fail to bring about successes in the impact and falling dart tests of item e, above, the entire molding lot shall be rejected.

g. Once the adjustments have been completed and the test units have successfully passed the rigors of item e, above, move the in- and out-feed systems into communication with the radio frequency generator.

h. Adjust the height of the in-feed system to centrally locate the projectile bands in the work coil.

i. Load the in-feed system with projectiles and pass a few through the bonding sequence, into the quench bath, and through the out-feed system. Subject these units to the impact tests of item e, above.

j. After set up has been established, operational bonding can begin.

4.2. Operation

a. Nylon 12 banded projectiles must be induction bonded within 48 hours of molding in order that absorbed moisture from the environment be at a level which will not be deleterious to the bonding process. Ascertain that the projectiles being bonded satisfy this requirement. Outdated projectiles cannot be used and must be rejected.

b. Load the projectiles into the in-feed system. The equipment will automatically feed them to the work coil, the bond will be consummated, the projectile will drop into the quench bath, and the ladder conveyor will carry the bonded units through the drying area.

c. Units at random shall be subjected to the impact engraving and falling dart tests of DeBell & Richardson Specification DRTP 6065.2.1, paragraphs 3.4 and 3.5, without failure. Failure will be cause for rejection of all the units from the previous successful testing.

4.3. Inspection

Periodic inspection of the set-up shall be maintained throughout the bonding process.

APPENDIX B

TEST PROCEDURE DRTP 6065.2.1

LABORATORY TEST METHODS FOR THE EVALUATION OF PLASTIC MATERIALS FOR PROJECTILE ROTATING BANDS

TEST PROCEDURE DRTP 6065.2.1

LABORATORY TEST METHODS FOR THE EVALUATION OF PLASTIC MATERIALS FOR PROJECTILE ROTATING BANDS

1. SCOPE

This specification delineates the procedures to be used in the laboratory evaluation of plastic materials for projectile rotating band applications.

2. REFERENCE DOCUMENTS

The following documents form a part of this specification to the extent intended herein:

2.1. Military Specifications

MIL-STD-810B	Environmental Test Methods

2.2. Federal Specifications

TT-C-490B	Cleaning Methods and Pretreatment of Ferrous Surfaces for Organic Coatings

3. METHODS AND PROCEDURES

The methods and procedures presented herein shall be used in the laboratory evaluation of plastic materials for use as rotating bands for projectiles.

3.1. Ring Shear Test

The ring shear test shall be used for the evaluation of the bond strength of a plastic material to a metal substrate through an adhesive primer system.

3.1.1. Test Specimen

The test specimen shall consist of a metal bar which has been treated with applicable surface preparations and coated with an adhesive/primer upon which a plastic band has been molded and bonded using conditions similar to those which would be or have been used for actual projectiles. The bar and its band can be any size and shape adaptable to available equipment, but the length of the band in shear should be approximately 40 percent of the bar diameter and the thickness should be approximately 1/3 of the band length. A suitable specimen description would be a metal bar of 1 inch diameter and 2 inches in length upon which a 3/8-inch-long by 1/8-inch-thick plastic band has been molded and bonded. Steel bars may be bare metal or zinc phosphated in accordance with Federal Specification TT-C-490B, in fine grain, minimum weight, and dust-free phosphate, and aluminum bars may be bare or anodized.

3.1.2. Test Fixtures and Equipment

The test fixture shall consist of a steel cavity having a bore diameter equal to the diameter of the test bar, plus 0.005 inch for diametral clearance. The cavity shall be concentrically counterbored to a depth equal to the test bar band length and at a diameter equal or slightly less than the band diameter in order that the banded test bar fit snugly with the counterbored seat. The face of the counterbored seat shall be flat.

The cavity shall be mountable within a compression testing machine, such as an Instron Model TTC-Ml, with a variable loading range.

3.1.3. Procedures

The following procedures shall be used in performing the ring shear test:

a. Subject the test bar and test cavity to the required environmental conditioning.

b. Load the test specimen into the counterbored test cavity and position the loaded cavity in the compression test machine.

c. At a slow rate, such as 0.05 inch/minute, load the test bar from the exposed metal end.

d. While recording the loading profile, continue loading the test bar until failure of the bond between the ring and the metal bar occurs. Allow the loading to continue, without recording, until the band has been displaced at least its full length.

e. Repeat the above for a minimum of 5 test samples at each environmental conditioning.

f. Observe and record the type of failure, e.g., plastic to primer, primer to substrate, a combination of these, the material in compression, etc.

g. Compute the ring shear strength from the average load divided by the shear area (product of 3.1416 times the bar diameter times the band length) and record.

3.2. Static Shear Test

The static shear test shall be used to measure the shear strength of a plastic material for use as a rotating band.

3.2.1. Test Specimen

The specimen shall consist of a disc of plastic material of suitable dimensions for testing. An acceptable specimen would be 1-1/2 inches in diameter and 1/8-inch thick. Specimen shall be molded as close as possible to conditions expected for projectile processing.

3.2.2. Test Fixtures and Equipment

The test fixture shall consist of a pair of flat steel plates between which the material specimen can be clamped. In the center of the plates and concentrically aligned shall be a pilot hole to receive a shearing punch. The shearing punch shall be of a diameter to freely slip in the fixture hole, but the clearance shall not exceed 0.003 inch. The punch shall also be of a length suitable for loading by a standard compression tester, such as an Instron Model TTC-Ml, at variable loading rates. A suitable punch diameter would be 5/8 inch.

3.2.3. Procedures

The following procedures shall be used in performing the static shear test:

a. Condition the test fixture, the shearing punch, and the material specimen at the desired temperature or environmental condition.

b. Install the specimen in the fixture and place the system in the compression tester.

c. At a slow rate, such as 0.05 inch/minute, load the shearing punch from the exposed end.

d. While recording the loading profile, continue loading the shearing punch through the ultimate strength until the load reaches an apparent no load condition.

e. Repeat the above for a minimum of 5 test samples at each environmental conditioning.

f. Disassemble the test fixture and examine the specimen for the type of failure, e.g., malleable, brittle, etc. Record the observations.

g. Compute the material static shear strength from the average load divided by the shear area (product of 3.1416 times the punch diameter times the specimen thickness) and record the results.

3.3. Wear Test

The wear test shall be used to determine a relative wear factor for a material for comparison with known standards in actual firing environments. This is a preliminary test method.

3.3.1. Test Specimen

The test specimen shall consist of a rectangular, round, or otherwise regular geometric shaped bar of material which has been molded and otherwise post-treated as would be in actual projectile rotation band processing. It shall be capable of being rigidly mounted in the test fixturing without relative bending. Specimen can be obtained from the runners of molded rotating bands, and they can be machined for area reduction. Satisfactory specimens have been approximately 3/16 inch square by 1 inch in length.

3.3.2. Test Fixtures and Equipment

The test equipment shall consist of a smooth rotating wheel with a surface velocity capability in excess of 400 feet per second. The surface roughness of the wheel shall be consistent with the surface roughness of rifled barrels. The wheel shall be driven by a suitable motor, and its speed shall be monitorable.

A holder for mounting the material specimen shall be attached to a variable loading device mounted on a cam system capable of loading the specimen against the wheel for a fraction of a second. The holder shall be instrumented for measuring material displacement versus time, and a load cell shall be positioned under the holder and perpendicular to the line of action. It shall be suitably instrumental so that measurements of the frictional force can be measured. Recording can be made by oscilloscope traces or by other positive recording devices.

An acceptable device uses an electric motor-driven rotating wheel with a 32-rms microinch surface roughness and a surface speed of 432 feet/second. The holding fixture is affixed to a pneumatic cylinder and is always under pneumatic pressure. A motor-driven cam allows the held specimen to be pressed onto the wheel and quickly retracted within 1/8 second. An oscilloscope with a camera is used to measure the friction load and the displacement, both versus time.

3.3.3. Procedures

The following procedures shall be used for the wear testing and determination of wear factors:

a. Condition the specimen holder and the specimen at the desired test temperature or environmental condition.

b. Start the equipment and allow it to come up to speed. Check out all instrumentation.

c. Quickly load the conditioned specimen and holder into the apparatus, set and record the loading pressure, and load the specimen against the wheel.

d. Using a strobotach, observe and record the wheel speed (in rpm).

e. Observe and photograph the displacement and friction force curves versus time from the oscilloscope.

f. Remove the specimen from the holder and carefully measure its dimensions in an undistorted zone. Observe and record the type of surface wear seen on the specimen.

g. Clean the wheel surface with bronze wool or other suitable soft cleaning medium.

h. Repeat the above for a total of 5 specimens at each environmental condition.

i. Repeat the above at three additional loading levels. (For example, specimen bearing stress levels in a geometric progression of 250, 500, 1000, and 2000 psi can be used.)

3.3.4. Calculations

From the data the following calculations shall be made:

a. For each group of 5 specimens, average the rotational speed and compute the average surface velocity from:

$$V = \frac{3.1416 \text{ X (rpm) X } D}{60}$$

where,

V = the surface velocity in feet/second

(rpm) = the average rotational speed in revolutions per minute

D = the diameter of the wheel in feet

b. From the oscilloscope photographs for each group of 5 specimens, determine the displacement for a fixed value of time. Divide the displacement by the fixed time for each specimen, and average these values for the 5 specimens to give a wear factor, w_f. Record w_f with the corresponding value of V.

c. For each group of 5 specimens, calculate the individual areas from the geometric shape data. Divide the recorded pneumatic pressures by each of the specimen areas, average the sum, and multiply the average by the pneumatic piston area to yield an average pressure, P, for the group. Record P with the corresponding values of V and w_f.

d. From the oscilloscope photographs for each group of 5 specimens, determine the individual friction forces. Divide each of these into the product of the individual pneumatic pressure and calculated specimen area. Average the sum of the 5 specimens to give a friction coefficient, μ. Record μ with the corresponding values of P, V, and w_f.

e. For each 5-specimen group, calculate the product of P and V. Record the result versus the other calculated values.

f. Calculate and record the logarithms of the PV product, μ, and w_f.

g. Plot log w_f and log μ versus log (PV) for the material at the four PV conditions at each environmental conditioning on orthogonal grid paper on as wide a scale as possible. Approximate a connection of the four data points with a straight line.

h. From the plot of $\log w_f$ versus $\log (PV)$, establish two points, a and b, on the straight line. Determine the wear equation from the following relationship:

$$w_f = (PV)^r \frac{w_{fb}}{(PV)_b^{\ r}}$$

where,

$$r = \frac{\log w_{fa} - \log w_{fb}}{\log (PV)_a - \log (PV)_b}$$

i. From the plot of $\log \mu$ versus $\log (PV)$, establish two points, m and n, on the straight line. Determine the friction coefficient equation from the following relationship:

$$\mu = (PV)^s \frac{\mu_n}{(PV)_n^{\ s}}$$

where,

$$s = \frac{\log \mu_m - \log \mu_n}{\log (PV)_m - \log (PV)_n}$$

j. From the above equations, calculate w_f and μ at $(PV) = 6 \times 10^7$ psi-ft/sec. Record the values for the respective environmental conditions.

3.4. Impact Engraving Test

The impact engraving test shall be used to evaluate plastic rotating bands on projectiles under simulated shot-start conditions.

3.4.1. Test Specimen

The test specimen shall be actual projectiles with plastic rotating bands manufactured under test or production conditions.

3.4.2. Test Apparatus

The test apparatus shall consist of a section of rifled barrel with forcing cone detail. The length of the rifled section shall be equal to the length of the projectile from the nose to the rear of the rotating band, plus the length of the forcing cone taper, plus approximately 1/8 inch. The rifled section shall be mounted to a steel plate, and the plate shall have a small hole concentric to the barrel diameter, with a dimension sufficient to insert a driving pin of adequate size for driving out a projectile after impact engraving.

The impactor shall be a 20-pound bar in sliding communication with a guide tube. One end of the bar shall be flat for impact with the projectile, and the other shall be attached to a lifting release line.

3.4.3. Procedures

The following procedures shall be used for the performance of the impact engraving test:

a. Set up the apparatus.

b. Condition the projectiles at the required temperature or environmental condition.

c. Place the conditioned projectile, nose down, into the rifled section of the apparatus.

d. Raise the impacting bar to the required height (usually 3 feet for a 60 foot-pound energy level) and release it to impact upon the butt of the projectile, thus driving it into the rifled section and impacting it against the steel base plate.

e. Remove the projectile from the fixture by using a drive pin from the nose end of the fixture.

f. Visually examine the projectile for any deleterious effects, such as debonding, chunking, fracture, etc. Record the observations.

3.5. Falling Dart Test

The falling dart test shall be used to evaluate the bond strength of projectiles having bonded rotating bands under impact conditions.

3.5.1. Test Specimen

The test specimen shall be actual projectiles with plastic rotating bands manufactured under test or production conditions. They can also be units which have withstood the rigors of the impact engraving test (see paragraph 3.4).

3.5.2. Test Apparatus

The test apparatus shall consist of a holder which snugly nests the projectile about the rotation band and bourrelet while exposing an approximate quadrant of the band for impaction. The holder shall be made of steel.

The impactor shall be a 20-pound bar in sliding communication with a guide tube. One end of the bar shall have an impressing brale of rifling land dimensions, and the brale length shall be slightly less than the width of the band seat of the projectile. The other end shall be attached to a lifting release line. The brale end can be removable from the bar, and it shall be hardened and shock resistant.

3.5.3. Procedures

The following procedures shall be used in the performance of the falling dart test:

a. Set up the apparatus.

b. Condition the projectile at the required temperature or environmental condition.

c. Place the conditioned projectile horizontally in the holding fixture and tighten the clamp snugly.

d. Raise the impacting bar to the required height (usually 3 feet for a 60 foot-pound energy level) and release it to impact the center of the rotating band.

e. Remove the projectile from the fixture and examine it for any deleterious effects, such as debonding outside the impace zone, chunking, fracture, propagated delamination, etc. Record the observations.

3.6. Temperature and Humidity Tests

Temperature and humidity are considered to be the most difficult environments for bonded projectile plastic rotating bands. This testing may be applied to projectiles or to test bars, such as those described in paragraph 3.1.1. The procedures shall be as described in MIL-STD-810B, Method 507, Procedure IV, for a 28-day cycle. After the exposure period the projectiles or test bars shall not show evidence of corrosion under the rotation band.

3.7. Peel Tests

Peel testing is virtually impossible to perform on projectiles which have not been subjected to some environmental conditioning having temperature and humidity. This testing, therefore, shall be accomplished on projectiles that have been so conditioned.

3.7.1. Test Specimen

The test specimen shall be regular or developmental projectiles with plastic rotating bands that have been conditioned in accordance with paragraph 3.6, above. After conditioning, a pilot hole shall be drilled in the butt of the projectile concentric to the bourrelet diameter.

3.7.2. Test Fixtures and Equipment

The test fixture shall consist of a centering holder in which the projectile specimen can be restrained in rotational communication. The fixture shall be used in conjunction with a tensile tester, such as an Instron Model TTC-M1.

3.7.3. Procedures

The following procedures shall be used in the performance of the peel test:

a. Remove the conditioned projectiles from the environmental chamber and allow them to equalize at ambient conditions for 24 hours.

b. With a sharp knife, cut down through the rotating band to the band seat, working and prying to lift a peel tab at least 1/4 inch in length.

c. Mount the projectile between the spindles of the test fixture and connect the jaws of the tensile tester to the peel tab.

d. Using a slow loading rate, such as 0.05 inch/minute, begin peeling the rotating band from the projectile while recording the peeling load.

e. Compute and record the average peeling load from the strip chart. Observe and record the maximum peel value.

f. Compute the average and peak peel strengths by dividing the respective loads by the band width. An acceptable value for 20mm projectiles is 30 pounds per inch.

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