



DEPARTMENT OF THE ARMY
U.S. ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BENET WEAPONS LABORATORY, LCHSL
WATERVLIET ARSENAL, WATERVLIET, N.Y. 12189

DRDAR-LCB-SE

1 September 1982

SUBJECT: Final Technical Report

TO: Commander
U. S. Army Armament Materiel Readiness Command
Attn: DRSAR-IRM
Rock Island, Illinois 61299

Project No: 6(77-79)7726

Project Title: Application of Cold and Warm Rotary Forging

Project Officer: L. Liuzzi

Statement of the Problem: Hot forging capabilities of the rotary forging process are recognized and the major forging parameters well defined. However, both warm and cold forging (at ambient temperatures) parameters of alloy steels used for cannon and related components are relatively unknown. Their definition will permit an expansion of the rotary forge machine's capability and utilization toward mission items.

Project Objective: The project objective was to extend the capabilities of the Rotary Forge Integrated Line by providing production data for warm and cold forging. It has been demonstrated that cold forging of thin-wall cannon with finished bores (rifled) is feasible by the rotary forge process. A limited number of thin-wall rifled and smooth bores have been forged as a result of prior years' projects and during the acceptance tests of the rotary forge machine. The proposed work will draw on the results from these programs to produce thin-wall tubes that meet the drawing requirements. This is the third phase of a three-year MMT effort. With FY77 funding, tooling was procured and the development of processing parameters initiated. With FY78 funding, preforms produced by various processes were purchased, modifications to the tooling was made and processing parameters refined to improve surface finish and tolerance control. The FY79 included prototype cold forging and final reporting.

This project was accomplished as part of the US Army Manufacturing Technology program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques and equipment for use in production of Army materiel.

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SUBJECT: Final Technical Report

1 September 1982

Background and Introduction: The development of the radial forging process has revolutionized production of large-caliber guns and rifle barrels. This method of manufacture, together with significant savings in critical materials and energy, offers the advantage of lower unit cost compared to other conventional methods. A large GFM radial-forging machine (SHP55) with numerical control was installed for the manufacture of gun barrels at Watervliet Arsenal. This machine has capacity for both hot and cold forging of hollow or solid cylinders having maximum starting diameters of 550 mm and a minimum bore of 65 mm; and can forge tubes up to a maximum length of 10 m. This equipment currently represents the most advanced manufacturing technology for gun-barrel fabrication in terms of cost, quality, precision, material and energy conservation.

Hot-forging capabilities of the radial-forging process are well recognized and the major forging parameters have been fairly well-defined. Analyses of the stresses, metal flow, and temperatures for optimizing the radial-forging process for manufacturing gun barrels were conducted under earlier studies.⁽¹⁻³⁾ Cold rotary swaging of precision gun barrels⁽⁴⁾ and cold radial forging of 7.62mm rifle barrels from super alloys⁽⁵⁾ have also been investigated. However, both cold forging (forging at room temperature) and warm forging (forging at temperatures well below the normal hot-working range) of large-caliber gun tubes from alloy steel are still unexplored, and cold/warm working parameters of the alloy steels used for gun and rifle barrels and similar components are relatively unknown.

Cold and warm radial-forging processes offer savings due to reduced needs for energy and equipment, and are capable of producing finished bores. In fact, it has been demonstrated that cold forging of thin-walled rifle barrels (with and without rifling) is feasible by the radial forging process.⁽⁶⁾ This results in cost savings due to a reduction in the number of machining operations required to produce the finished product. Thus, characterization of process parameters for cold and warm forging represented an opportunity for expansion of the capabilities and utilization of the radial-forging machine.

Approach to the Problem: Previous years efforts were centered about establishing the optimization of the hot forging parameters for the radial forging process. These studies resulted in

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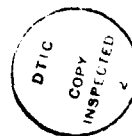
1 September 1982

several computer programs to predict stresses, loads, power, metal flow, and temperature distributions during the radial forging process.

Using this earlier work as a base, a contract was awarded to Battelle Columbus Laboratories, to expand the optimization of the radial forge computer programs to include application to the warm and cold modes of forging. Ring tests were conducted to determine the friction factors and flow stresses of gun steel at warm and cold forging temperatures. In addition, mechanical properties of the test materials were taken to determine what the temper embrittlement behavior of gun steel would be at warm forging temperatures.

The 106mm Recoil Rifle, was used as a test vehicle for the cold forging trials for thin-wall tubes. Seamless tubing was purchased and machined to the preform configuration to allow for 10, 15 and 20% reductions during forging. During the progress of this project considerable delays were encountered primarily because of production priorities and several machine malfunctions which had to be corrected. Eight 106mm Recoil Rifles then were cold forged to the finished bore configuration. The tubes were then visually and dimensionally inspected.

Originally it was felt that warm forging was one method to expand the capability of the forge machine to allow forging of thick-wall tubes to close tolerances and eliminate some of the rough machining normally done on the hot forged tubes. However, the logistics of maintaining a uniform temperature of 900 - 1000°F on the larger forgings (105mm and 155mm) proved impractical with the existing equipment. Therefore, it was determined that a 105mm M68 hot forged blank would be cold forged to the pre-autofrettaged bore dimensions to test the upper limit of the SHP55 machine. Two performs were hot forged to a modified configuration that was to be used as the blank in cold forging. The dimensions of the blanks allowed for a 10% and 20% forging reduction. Two 105mm M68 blanks were cold forged to the pre-autofrettage configuration.



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DRDAR-LCB-SE

SUBJECT: Final Technical Report

1 September 1982

Results and Discussion: The results from the optimization program for the warm radial forging showed the following:

- a. It is possible to warm radial forge the 105mm M68 gun tube. However, care should be taken not to forge the material in the embrittlement range (427 C/800 F to 538 C/1000 F).
- b. The geometry of the tool has to be designed in such a way not to exceed the capacity of the machine - this means that both the entry angles and contact angle of the tool with the workpiece had to be designed to limit the load requirements within the capacity of the machine.

Based on the analysis with different tool geometries, preform dimensions and preconditions (lubricated or non-lubricated), the following was recommended:

- a. Warm radial forging of the muzzle end was recommended to be done under the following conditions:
 - (1) Forging temperature 400 C - 424 C (750 F - 800 F).
 - (2) Reduction for non-lubricated condition - 15 percent maximum.
Reduction for lubricated conditions - 20 percent maximum.
 - (3) Contact Angle - less than or equal to 60 degrees for non-lubricated preform
- less than or equal to 75 degrees for lubricated preform.
 - (4) Tools - cold forging tools with a compound entry angle of 5 degrees and 2 degrees.
- the tool configurations should be relieved beyond the contact angle specified.

1 September 1982

- b. Warm radial forging of the breech end was recommended to be done under the following conditions:
- (1) Temperature of forging - 400 C - 425 C (750 F - 800 F).
 - (2) Reduction - non-lubricated condition = 10 percent maximum
- lubricated condition = 10 percent maximum
 - (3) Contact angle - non-lubricated condition \leq 75 degrees.
- lubricated condition \leq 75 degrees.
 - (4) Tools - cold forging tools with a compound entry angle of 5 degrees and 2 degrees - the tool configuration should be relieved beyond the contact angle.
- c. Care has to be taken to maintain the temperature in the specified range - higher temperatures would result in the working of the component in the temper-embrittlement range.
- d. Problems envisaged are:
- (1) Maintenance of temperature and mode of heating of the billet.
 - (2) Lubricant application.
 - (3) Secondary handling of the billet for the final operation.
 - (4) Selection of tool material.

As previously mentioned, the logistics of maintaining the temperature and mode of heating precluded actual warm forging under these conditions. The specific details of the Battelle study are given in Reference 8.

A summary of the dimensional results of the cold forged 106mm Recoil Rifles (Figure 1) is given in Table I. As seen

DRDAR-LCB-SE

SUBJECT: Final Technical Report

1 September 1982

from the data, cold forging of thin-wall tubes with a finished rifling can be produced. A cross section of the rifling is shown in Figure 2.

The first 105mm M68 blank was designed to have an overall reduction of 10% (muzzle to breech). However, a machine malfunction did not permit completing the forging cycle on this preform. The second preform designed for a uniform 20% reduction was then cold forged. Although the material was at the 175,000 psi yield strength level, the tube was forged well within the capacity of the SHP 55 machine. The mandrel provided a bore size equivalent to the pre-autofrettage dimension. This first successful forging of a 105mm M68 indicates the feasibility of using this technique on the thick-wall tubes (Figure 3). This would have the potential of going directly from the hot forging configuration to cold forging, a pre-autofrettage configuration. Intermediate machining (rough honing) would only be needed to clean the bore scale. This could possibly eliminate the boring of the tube and other rough machining operations necessary prior to autofrettage.

Because of production requirements, the remaining 105mm blanks could not be forged to verify the initial results. It is anticipated to continue this work at some future date with other funding.

Conclusions: Thin-wall tubes, such as the 106mm Recoil Rifles, can be cold forged with the rifling.

The project also demonstrated the capability of the SHP55 rotary forge machine to cold forge tubes at the 170,000 psi yield strength level with wall thicknesses ranging up to three inches.

It was also shown that it is feasible to cold forge the 105mm M68 to the pre-autofrettage configuration.

Economic Benefits: The present conventional machining of a 106mm Recoil Rifle takes 19.40 hours. With the rotary forging of the same tube, machining can be reduced to 12.80 hours providing an effective savings of 6.60 hours. The initial results with the 105mm M68 are insufficient at this time to determine what economic benefits can be derived.

DRDAR-LCB-SE
SUBJECT: Final Technical Report

1 September 1982

Implementation: The 106mm Recoil Rifle is no longer manufactured at Watervliet Arsenal and, therefore, cannot be implemented at this time. Implementation of the 105mm M68 cold forging depends on results from future studies.


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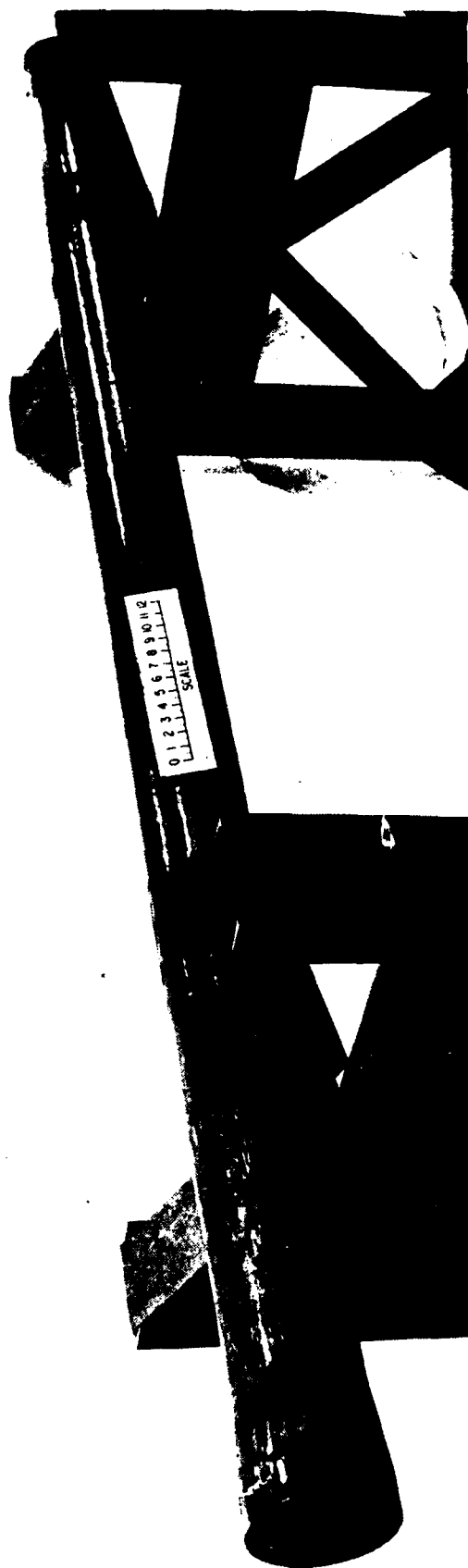


Figure 1. Cold Forged 106mm Recoil
Rifle

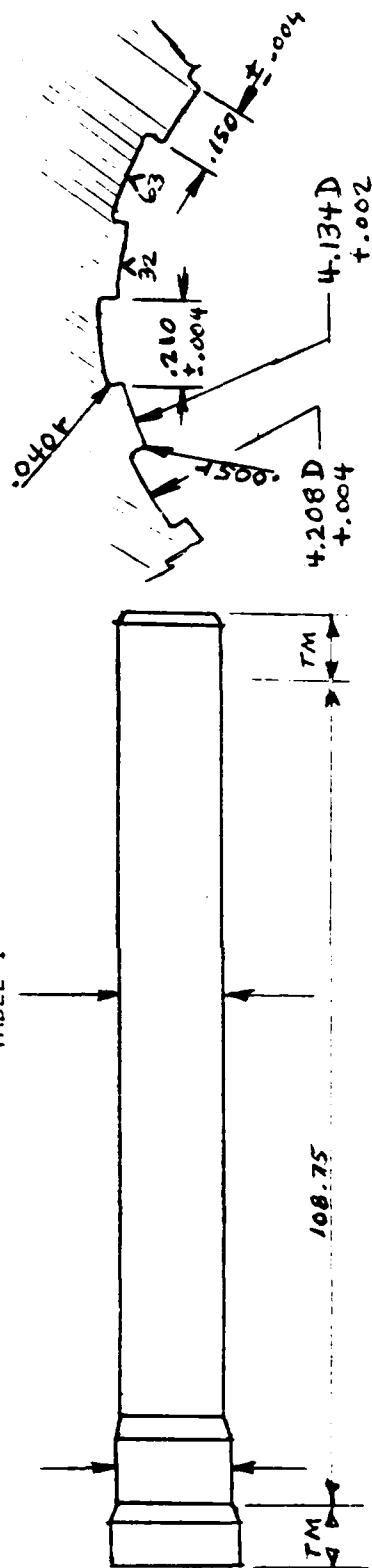


Figure 2. Cross-section of rifling
configuration in cold forged
106mm Recoil Rifle



Figure 3. Cold forged 105mm M68

TABLE I



No.	O.D.	RIFLING DIA.			Groove Width	Rifling Twist 1/83.26"	OD Chamber	Forging Cycle (Min.)	Wall Variation	Red.	Note
		Bore Groove	Land	Ovality							
1	-----	-Used for machine set-up-			-----	-----	-----	-----	-----	-----	-----
2	5.204	OK	OK	.0005	.206	-.40	6.030	10	.008	10%	
3	5.204	OK	OK	.0005	.206	-.40	6.030	10	.012	10%	
4	5.128	OK	OK	.0005	.206	-.40	-	10	.013	15%	Breech not forged machine malfunction
5	5.234	OK	OK	.0005	.206	-.40	6.030	10	.010	15%	
6	5.461	OK	OK	.0005	.206	-.40	6.119	10	.012	15%	
7	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	Tape malfunction
8	5.422	OK	OK	.0005	.206	-.40	-	10	.010	20%	Breech not forged machine malfunction