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RECYCLING OF SCRAP GUN TUBES BY ROTARY FORGING

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Preform	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Recycling of gun tubes has been a two-year MM&T effort by the Advanced Engineering Section of Benet Weapons Lab at Watervliet Arsenal. The basic approach involves rotary forging of scrap (fired-out, mismachined, obsolete, etc.) tubes directly into a new tube forging of smaller size without any intermediate melting operation.

The preliminary phase or first year's effort of this project determined the quantities of scrap tubes available for recycling and future tube production cont'd.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) requirements. This phase was then followed by processing a sample quantity of scrap tubes from the field. Since tubes with the largest volume of material showed the most potential for recycling, emphasis was placed on locating larger tubes; namely, 8" M2A2 and 175mm M113 gun tubes. Other tube models, such as the 155mm M185, were also included in the study. The samples of selected tubes were then inspected for the extent of damage. Based on the firing damage, a standard machining procedure was established to prepare a tube for recycling.

A computer program was then developed which, based on tube dimensions, generates an optimum mix of new tubes that can be produced giving the required preform dimensions. Based on this computer program, scrap tubes were cut and recycled through the Rotary Forge.

The overall results proved that scrap tubes can be made into acceptable forgings that meet the dimensional drawing requirements. The follow-up heat treatment and mechanical property testing resulted in less than half of the tubes meeting the required mechanical properties. However, in analyzing these results, the older scrap tubes produced by air melting practices, resulted in very few with acceptable mechanical properties. The scrap tubes of a more recent vintage originally produced from newer melting practices such as, vacuum degassing, vacuum deoxidizing, and electroslag refining resulted in nearly 100% with acceptable mechanical properties.

The recycling program will result in substantial cost savings when applied to scrap tubes originally produced from the newer melting practices.

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INTRODUCTION

With the advent of the rotary forge system at Watervliet Arsenal, a number of suggestions were made to expand the utilization of the rotary forge. Among these suggestions was one to recycle scrap tubes through the forge rather than to use them for scrap for remelting. Since the suggestion appeared to have merit and potential for considerable savings, funding was obtained through the Manufacturing Technology Program.

The project was a two-year effort which was divided into two phases. The first phase was aimed at determining the quantity of scrap* tubes available for recycling, the mix (various models), development of a computer program for optimizing what the scrap tubes could be reforged into and an inspection procedure for extent of firing damage. The second phase was implementation of the results through a series of forging trials.

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* For the purpose of this report, scrap tube shall be defined as any gun tube which is intact. They shall include, but not be limited to, fired out, obsolete, and mismachined gun tubes.

APPROACH TO THE PROBLEM

Tube Models to be Considered

The first step which was taken to initiate the rotary forge recycling project was to determine which tubes of past, present and future production should be considered for recycling. This was based on usable volume and material distribution. The volume of material necessary for recycling was established from the volume requirements of tubes produced by the rotary forge. The tube models that were selected in this initial step were categorized into the following groups:

Scrap Tubes Considered For Recycling	Tubes to be Produced From Scrap Tubes
155mm M1 (also M1A1)	90mm M41
155mm M126A1	105mm M2A2
155mm M185	105mm M68
175mm M113 (also M113E1)	105mm M137A1
8" M47	105mm XM205
8" M2A2	152mm M81E1
8" M201	155mm M1 (also M1A1)
	155mm M185

Establishing Available Quantities of Scrap Tubes

A study was made from the list of scrap tubes considered for recycling to establish in what quantities these tubes were available for recycling. This was performed by the product manager of each gun model on a best guess effort. Many of these tubes go back into the 1950's and it is difficult to determine how many are remaining world-wide.

Sample Inspection of Scrap Tubes

The next step involved recovery of the following tubes from the field:

Quantity	Tube Model
6	155mm M126E1
3	8" M47
4	8" M2A2
4	175mm M113

These tubes had all remaining parts removed and they were cleaned to allow for a thorough inspection of firing damage. This included a visual inspection of the outside surface, a borescope inspection of the bore and an ultrasonic inspection of the entire tube concentrating primarily near the origin of rifling. Based on the tube inspections, it was decided that removal of the rifling plus .050" of material (.025" on a side) in the bore would be sufficient to eliminate firing damage existing in the tubes.

Computer Program

A computer program (in FORTRAN) was written to calculate which gun tubes can be rotary forged from a scrap tube.

In generating the computer program, the following general assumptions were made:

1. There had to be enough usable volume to forge the desired gun tube.
2. The reduction in cross-sectional area had to be between 5 and 1.1 to 1.
3. The preform obtained from the recycled tube had to be less than 180 inches long.
4. Clearance between the mandrel and starting blank had to be between .5 and 3 inches.

5. The outside diameter of the preform had to be greater than the outside diameter of the tube being made.

The reasons for assumptions one and five are, of course, obvious. Assumptions two and four were obtained from previous rotary forging experience. Assumption three resulted from a length restriction for the induction heating system.

Program input consisted of the dimensions of the tubes to be recycled and the dimensions of the tubes to be made. This input included the volume, outside diameters, inside diameters, and lengths for each gun tube. The output information tells whether the tube can be made based on the five conditions given above. Failure to meet any of the five conditions will result in the program printing the reason for failure. There are two exceptions to this. If the reduction requirement is greater than 5 to 1 or if the clearance between the mandrel and the recycled tube inside diameter is greater than 3 inches, then the program will calculate dimensions for forging an intermediate preform. The intermediate preform is a right circular cylinder that is forged from the original scrap tube. The final tube is then forged from the intermediate preform. If an increase in wall thickness will occur, the largest increase is printed, although this condition is not used as a reason for failure to make a tube. A detailed description of the program is given in Appendix A.

Tube Preparation for Recycling

To prepare tubes for recycling, the first step was to have all parts removed. This involved removal of the breech mechanism and machining off of the hoops and rails.

For the preliminary recycling trials, it was decided that no other machining would be performed on the tubes except for removal of firing damage and cutting the tubes to the required length for the proper volume.

Forging, Heat Treatment, and Testing

The machined preforms were preheated in the Cheston induction furnace (integral part of the Rotary Forge Integrated line) and forged on the rotary forge using specially prepared NC tapes to instruct the rotary forge. After forging, the tubes were cooled and discards cut off the breech and muzzle prior to heat treatment. The cutting of discards is a standard procedure which is performed on all tubes to avoid potential cracking problems in the heat treat cycle. The tubes were heat treated in the Selas Heat Treat System which is also part of the rotary forge integrated line. Following heat treatment, the tubes followed standard testing procedures by having a test disc cut from each end. The breech and muzzle end discs were then machined into two tensile and two charpy impact test specimens each and tested.

First Article Testing

The normal procedure to be followed when a new item is produced or a substantial change is introduced in an existing item is to require that First Article Testing be performed. This involves selecting one of the new items produced usually from prototype production and performing extensive mechanical property testing. The actual First Article Test requirements are imposed by or requested from Quality Assurance Directorate. Due to the large variations in tube manufacturers, melting practices, chemistries, and models, it had to be decided how first article testing would be applied to qualify scrap material for recycling into new production tubes.

Development of Screening of Criteria for Tube Selection

An important part in the approach to the problem was to establish criteria by which tubes could be selected to insure a high degree of reliability that acceptable recycled tubes could be produced. This required analyzing all available information on each scrap tube and comparing it to the results obtained on each recycled tube produced.

Economic Analysis

The last phase in the recycling program was to establish if it was economically beneficial to recycle scrap gun tubes versus the current conventional costs. This comparison was performed by adding all the costs involved in preparing a scrap tube up to the point of it being a preform for the rotary forge versus the conventional preform cost.

RESULTS AND DISCUSSION

Potential Scope for Recycling

The results of the study to determine available quantities of tubes for recycling are shown in Table 1. This table shows how many of each tube have been produced, how many are remaining available for recycling, and how many we can potentially expect to become available from future production.

Computer Screening and Tube Elimination

All necessary dimensions for the scrap tubes for recycling and the tubes to be produced were put into the computer and the program was run to generate working combinations of tubes that can be produced from a given scrap tube. In many cases, multiple tubes can be produced from one scrap tube. For example, four 105mm XM 205 gun tubes can be produced from one 8" M201 tube.

The computer program showed that none of the tubes listed to be produced could be made from the 155mm M1, 155mm M126A1 or the 155mm M185 with the assumptions given. Several combinations are possible for the other tubes listed for recycling. Due to anticipated high quantities becoming available of the 155mm M185, special emphasis was made to produce a 105mm M68 from the 155mm M185 gun tube. To date this has not been accomplished. Table 2 compares the scrap tube available in the field with tubes to be produced and shows where working combinations are possible.

Based on the potential quantities available, it was decided to initiate the recycling forging trials using 175mm M113 and 8" M2A2 tubes. The 155mm models were eliminated by the computer program and the 8" M201 tubes were not available. Future tube production was only available projected 18 months in the future.

Table 1 - POTENTIAL QUANTITIES OF GUN TUBES FOR RECYCLING

TUBE TYPE	QUANTITIES PRODUCED	POTENTIAL REMAINING QUANTITIES FOR RECYCLING	CURRENT YEARLY PRODUCTION
155mm M1	1954-1979	0	0
155mm M1A1	3,108	625	23
155mm M1A2		56	0
155mm M126	1954-1970	0	0
155mm M126A1	5,868	300	0
155mm M185	1972-1979		
	4,751	1728	622
175mm M113	1956-1979	3	0
175mm M113A1	5,788	107	33
8" M47	1959-1966		
	74	9	0
8" M2A1	1952-1979	0	20
8" M2A2	1,935	734	0
8" M201	1976-1979		
	1,289	891	451

Table 2 - POSSIBLE COMBINATIONS FOR RECYCLING

	SCRAP TUBES			
	175mm M113A1	155mm M185	8" M2A2	8" M201
90mm M41	X		X	X
105mm M137A1	X		X	X
105mm M68	X	?	X	X
105mm M2A2	X		X	X
105mm XM205	X		X	X
152mm M81E1	X		X	X
155mm M185	X		X	X
155mm M1			X	X
155mm M1A1			X	X

It was decided to concentrate our efforts on our current two high density items: the 105mm M68 and the 155mm M185 gun tubes. The recycling combinations for the 8" M2A2 and 175mm M113 tubes result in the same possibilities. Namely, from one scrap tube we are able to produce two 105mm M68's or one 155mm M185 gun tube.

Machining Required to Prepare Scrap Tubes for Recycling

The machining preparation of preforms for the initial recycling trials was purposely kept at a minimum in an attempt to determine which irregularities could be tolerated in all phases of the recycling process. The three main areas which were of concern were the preheating prior to forging, the actual forging operation, and the heat treating.

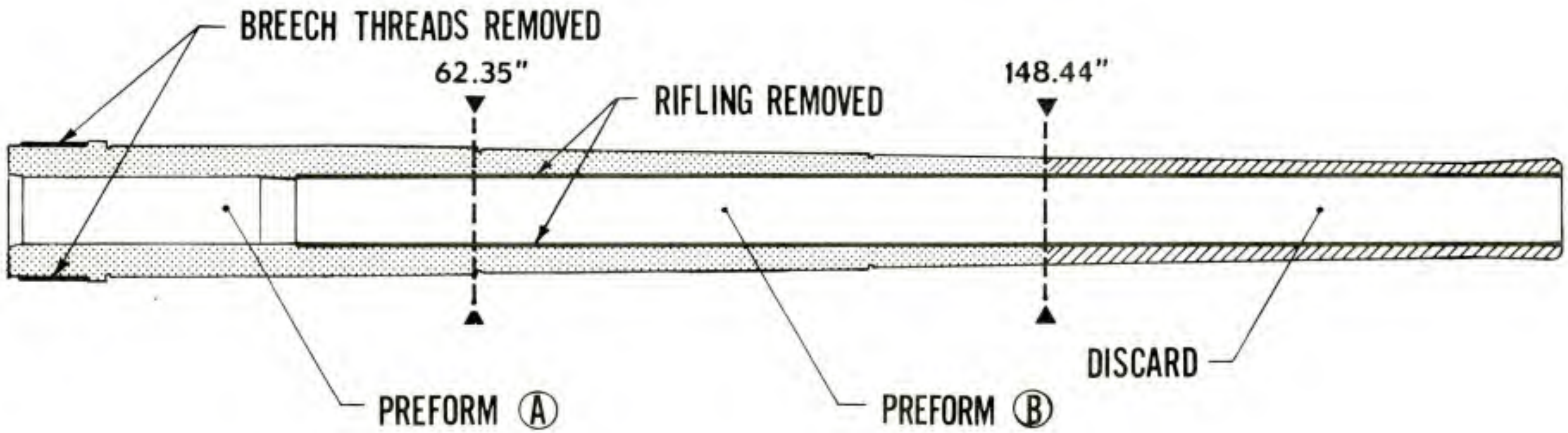
The initial recycling trials resulted in certain problems developing which led to additional machining requirements in preparing a section of a scrap tube for use as a rotary forge preform. The first problem encountered was with the oscillation of the preforms on the V-shaped rollers of the Cheston Induction furnace used for preheating. It was found that abrupt changes on the outside surface of the preform either in the form of a shoulder or a steep taper would result in erratic travel or catch on the rolls and stop the preforms' travel completely. The solution to this problem was to blend all adjacent outside diameters with a maximum 5^o angle. There are several types of special machining details that may be encountered in the several scrap tube models considered for recycling. These include items such as breech threads, longitudinal slots, keyways, tangential grooves and threaded holes drilled partially into the tube wall. These details did not present any problem in the preheating portion of the recycling procedure, but during the forging operation, they resulted in overlapping of material which went to depths of 1/4" or more. The overlapping of material cannot be accepted as it represents a potential area for cracking during heat treatment. Overlapping to the depths that were observed would possibly still be present as the tube is machined down to its final outside configuration, which would not be acceptable. The solution for these problems was to completely remove breech threads. All other tube details encountered were machined or benched such that the deepest portion was blended in all directions with a maximum 30° angle with the outside surface. It should be noted that tube areas which had through holes were not considered for recycling. Figure 1 shows how an 8" M2A2 is cut to produce two 105mm M68 preforms.

Initial Recycling Trials

As the recycling program got underway and initial recycling trials were completed, the ability to forge a given tube configuration from a scrap tube section was shown to be no problem as predicted by the computer program. However, two other problems did present themselves and necessitated considerable testing. The two problems which surfaced were: How do you select a scrap tube for recycling that has a high potential for obtaining mechanical property requirements in the recycled tube produced? Secondly, how do you prescribe the proper heat treat parameters for the recycled tube?

In the initial recycling trials, tubes were selected on a random basis (Tab. 3). After each scrap tube was forged, it was heat treated in the Selas Heat Treat System. Due to the large variations in chemistry and melting procedures used, it was decided to initially heat treat the recycled tubes along with standard production tubes of the same model using the same heat treat parameters. The mechanical property requirements for the 105mm M68 and the 155mm M185 gun tubes are both the same and are specified by MIL-S-46119A (MR) dated 7 March 1973. The mechanical property requirements as specified by this

FIGURE 1 - TYPICAL MACHINING REQUIRED FOR ROTARY FORGE TUBE RECYCLING



RECYCLING 8" M2A2 TO PRODUCE
PREFORMS FOR TWO 105mmM68's

Table 3 - TUBE SERIAL NUMBERS AND MODELS SELECTED FOR THE ORIGINAL RECYCLING TRIALS

Starting Tube		Resulting Tube(s)	
Tube #	Model	Tube #	Model
1553	8" M2A2	1553	155mm M185
4156	8" M2A2	4156	155mm M185
7213	8" M2A1E1	7213A 7213B	105mm M68 105mm M68
7429	8" M2A2	7429A 7429B	105mm M68 105mm M68
82	175mm M113	82	155mm M185
85	175mm M113	85	155mm M185
741	175mm M113	741A 741B	105mm M68 105mm M68
1214	175mm M113	1214A 1214B	105mm M68 105mm M68
23896	155mm M185	23898	105mm M68

Military Standard can be summarized as follows:

Yield Strength - Must be between 160,000 and 180,000 psi (also not greater than a 6000 psi spread in test specimens from the same transverse disc).

Reduction in Area - Must be equal to or greater than 25%.

Charpy Impact - Must be equal to or greater than 15 ft-lbs.

After heat treatment of each recycled tube, discs were cut and test specimens were machined and tested. In some cases where required mechanical properties were not met, additional heat treating and testing was performed either on the full size tube or on small coupons of the tube material. Results are shown in Table 4.

Establishing Heat Treat Parameters

The proper heat treatment of the recycled tubes at first presented a problem with such a wide range of chemistries. After several tubes were heat treated using various parameters and tested,the results began to fall into a pattern. The proper heat treatment appeared to have a degree of predictability when compared to the original tube producer. Our sample of tubes can be broken down into three categories by vendors. The tubes were made by Vendor A, Vendor B, and a small percentage were of unknown source.

The selection of heat treat parameters was narrowed down to running all tubes the same as standard production in the Selas Heat Treat System with the only variable to be selected being the proper tempering temperature. Some guidelines established for selecting the proper tempering temperature are as follows:

Table 4 - SUMMARY OF HEAT TREATMENTS AND MECHANICAL PROPERTIES FOR INITIAL RECYCLING

	HEAT TREATMENT			MECHANICAL PROPERTIES (avg)		
TUBE #	HEAT TREAT SPEC SIZE	AUSTENITIZE (°F/Hrs)	TEMPER (°F/Hrs)	YIELD STR (ksi)	RED IN AREA (%)	CHARPY IMPACT (ft lbs)
1553	155mm Tube	1550/4	1075/6-1/2	139.4	31.5	6.5
1553	"	1535/4	1070/6-1/2	130.6	25.4	4.5
4156	"	1550/4	1075/6-1/2	142.4	36.5	10.7
4156	"	1560/4	1070/6-1/2	172.8	26.6	7.0
4156	Coupon			168.8	32.3	8.3
7213A	105mm Tube	1550/2-1/2	1075/4	178.2	40.1	15.8
7213B	"	1550/2-1/2	1075/4	173.5	43.7	21.8
7429A	"	1560/2-1/2	1100/4	175.0	18.6	11.4
7429A	Coupon	1550/1	1110/1	162.3	19.4	14.8
7429A	"	1600/5	1100/1 1100/1	164.9	19.9	16.3
7429A	"	1550/1	1110/1 1100/1	167.1	17.6	16.7
7429A	"	1600/3	1100/1 1100) 1130)/1-1/2	160.6	31.2	18.0
7429A	"	1550/5	1130/1 1130/1	157.5	26.1	20.4
7429A	"	1600/3	1100&1130/1-1/2	161.2	34.3	19.0
7429A	"	1550/5	1100/1 1130/1	163.5	23.7	17.8
7429B	105mmTube	1560/2-1/2 *	1100/4	175.0	21.4	10.9
85	155mm Tube	1540/3	1115/5	180.1	13.0	13.4

* Normalized at 1750° for 2 hrs. prior to austenitizing.

Table 4 (cont'd)

	HEAT TREATMENT			MECHANICAL PROPERTIES (Avg)		
TUBE #	HEAT TREAT SPEC SIZE	AUSTENITIZE (°F/Hrs)	TEMPER (°F/Hrs.)	YIELD STR (ksi)	RED IN AREA (%)	CHARPY IMPACT (ft lbs)
85	Coupon	1600/3	1130/1 1130/1	168.6	30.8	20.8
85	"	1600/3	1130/2	171.5	21.2	20.7
741A	105mm Tube	1560/2-1/2	1100/4	175.4	11.5	15.4
741A	"	- -	1115/5	171.5	15.8	15.9
741B	"	1560/2-1/2	1100/4	175.9	17.4	15.0
1214A	"	1560/2-1/2	1100/4	180.4	24.0	13.5
1214A	"	- -	1113/5	176.3	18.8	13.1
1214A	"	1560/2-1/2	1100/4	179.7	20.4	13.4
23896	"	1545/3	1112/5	166.9	32.4	19.5

Tubes produced by Vendor A	1075°F
Tubes produced by Vendor B	1125°F
Unknown source*	1075°F

*(Retemper at higher tempering temperature as required)

Screening Procedure

Due to the large variations in scrap tubes which could be considered for recycling, it was necessary to have a procedure for screening. The first method chosen was to make selections based on tube chemistries. Table 5 shows the two basic chemistry ranges which were used for screening tubes. Earlier in the project it was not known what quality of mechanical property results would be obtainable from the recycled tubes. It was decided processing would have to be modified between the two chemistry ranges. The initial recycling trials showed this was not a reliable method of screening.

Based on earlier test results, 105mm M68 and final article testing scrap 8" M2A2 gun tubes were accepted on a conditional basis for preform material to produce production 105mm M68 gun tubes. The criterion chosen for deciding acceptability of each scrap tube was to take test discs approximately 6" from the muzzle end and have them heat treated and tested. The heat treatment selected was to austenitize each disc at 1550°F for one hour, water quench, and then follow by a two-hour tempering with the tempering temperature based on the manufacturer's chemistry. The sample of tubes used for muzzle testing fell into the same three groups previously discussed consisting of Vendor A, Vendor B, and unknown source. Heat treat parameters were selected as previously described.

Based on tube chemistries and the final mechanical property results obtained from each disc, it was decided which scrap tubes could be used for recycling and also what tempering temperature should be used to result in the acceptable property range required. The results of muzzle end testing

Table 5 - TWO NOMINAL CHEMISTRY RANGES CONSIDERED FOR RECYCLING OF GUN TUBES

	RANGE 1	RANGE 2
C	.28/.37	.28/.37
Mn	.45/.85	.45/.85
P	.020 MAX	.020 MAX
S	.020 MAX	.020 MAX
Si	.13/.35	.13/.35
Ni	.00/1.70	1.70/3.10
Cr	.80/1.30	.80/1.30
Mo	.30/.70	.30/.70
V	.00/.18	.00/.18

for the initial 106 tubes considered for production showed most tubes* in the following ranges:

Yield Strength	160-168 ksi
Charpy Impact	15-25 ft-lbs (at-40°F)
Reduction in Area	30-45%

* Tubes identified as vacuum degassed material in general have higher mechanical properties than shown in these typical ranges.

The mechanical properties obtained from the resulting 105mm M68 tubes showed the following ranges for most cases:

Yield Strength	159-168 ksi
Charpy Impact	12-20 ft-lbs (at -40°F)
Reduction in Area	19-40%

The changes in mechanical properties are due to many factors, some of which could be variations in chemistry within each tube, the added forging reduction, impurities in the steel and many other factors.

The range shift for the Charpy impact and the reduction in area resulted in unacceptable properties in many cases. This showed that using tube chemistries and mechanical properties from the muzzle end were not sufficient to predict acceptable recycled tubes.

Shortly after production use was initiated of recycling scrap 8" M2A2 gun tubes, it was decided that possibly breech end testing would be a more accurate means of determining the acceptable quality of the material for recycling. This was based on the breech end experiencing different forging reductions than the muzzle end; and because the breech end was where the pre-form was being taken, the muzzle ends were being discarded. Also during the breech end testing, it was decided to determine if a normalizing operation performed prior to our standard heat treatment would result in improved mechanical properties. To test this theory, breech discs 1" thick were cut directly off the breech end of 27 tubes. Next, each disc was cut in half on a diameter prior to heat treatment. This allowed for one half to be normalized at 1750^{o}F for two hours and air-cooled prior to our standard heat treatment. For the breech discs, the standard heat treatment used for all discs was austenitize at 1550oF for 1 hour, water quench, temper at 1075^{o}F for 2 hours and water quench.

In general the breech end testing showed the same property ranges as those found from the muzzle end testing. The addition of a normalizing operation prior to heat treatment showed up in slight increases in yield strength and charpy impact values but no noticeable change in the reduction in area. The increases were not significant over what might be considered normal testing error; and therefore the use of a normalizing operation was not considered worthwhile.

105mm M68 First Article Testing

The production use of recycled material required first article testing be performed. It was decided for the 105mm M68 to use chemistry range 2 for our first article testing. The tube selected was 105mm M68 tube #7213A, which was produced from an 8" M2A2 tube Serial Number 7213. Table 6 shows the chemical analysis of this tube along with special tramp elements which were required as part of the first article testing. Table 7 shows the actual mechanical properties obtained at the various required locations along the tube length. Also shown in Table 8 are K_{Ic} results obtained from tube 7213A that were not a required part of the first article testing. These results were equal to or better than most production tubes tested.

155mm M185 First Article Testing

When the time came for using recycled material for producing 155mm M185 tubes, first article testing was again required. The testing was performed much the same as for the 105mm M68 but the tube selection criteria

Table 6 - CHEMISTRY FOR RECYCLED 105MM M68 TUBE #7213A

ELEMENT	RANGE 2	ACTUAL
C	.28/.37	.33
Mn	.45/.85	.62
P	.020 Max	.011
S	.020 Max	.009
Si	.13/.35	.13
Ni	1.70/3.10	2.09
Cr	.80/1.30	.98
Mo	.30/.70	.47
V	.00/.18	.10
Cu		.086
AL		.004
Sn		.03
Sb		.01

Table 7 - MECHANICAL PROPERTY RESULTS OF FIRST ARTICLE TESTING OF RECYCLED 105MM M68 TUBE #7213A

LOCATION	Cv (ft-lbs)	Y.S. (KSI)	T.S. (KSI)	EL %	R.A. %
Breech End	24.5	176.2	189.7	15.0	46.6
	27.5	177.7	190.7	15.0	45.4
48" From Breech End	26.5	180.3	191.9	14.3	43.6
	28.3	179.2	189.7	15.7	46.2
60" From Breech End	27.5	180.7	191.2	15.0	45.8
	28.5	180.7	190.7	15.0	44.1
72" From Breech End	27.0	179.2	190.2	13.6	38.5
	27.0	180.3	191.9	13.6	43.6
103" From Breech End	25.5	174.7	188.7	15.0	45.4
	29.0	174.7	188.7	14.3	45.4
Muzzle End	26.7	171.7	185.7	15.7	45.4
	26.5	171.7	186.2	15.0	45.4

Table 8 - FRACTURE TOUGHNESS RESULTS FROM 105MM M68 TUBE #7213A

CODE NO.	SPECIMEN SIZE	Fracture Toughness K_{Ic} ksi $\sqrt{in.}$
13AZA1	1.5" "C"	142.5
13AZA2	1.5" "C"	137.5
13AZB1	1.5" C	143.1
13AZB2	1.5" C	145.9
13AZC1	1.5" C	144.9
13AZC2	1.5" C	145.5
13AZD1	1.5" C	143.9
13AZD2	1.5" C	141.7
13AZE1	1.0" C	128.9
13AZE2	1.0" C	123.5
13AZF1	1.0" C	124.6
13AZF2	1.0" C	128.6

were changed. As more testing was performed and more data gathered on recycling of tubes, it became apparent that tube chemistry was not a reliable method of determining if a tube would be usable to produce the required mechanical properties in the new tube produced. The manufacturer and the melting practice used surfaced to be the key variables in deciding the usability of a given scrap tube. The first article testing of a recycled 155mm M185 was performed much the same way as for the 105mm M68; but rather than specify a chemistry range, certain manufacturers and acceptable melting practices were cited. The acceptable newer melting practices are Vacuum Degassing, Vacuum Deoxidizing, and Electro-Slag Remelting using the techniques introduced in the late 1960's by Vendor B and 1970's by Vendor A.

Tube Serial Number 7459, a 175mm M113E1 tube produced by the Vacuum Deoxidizing melting practice, was selected. Table 9 shows the tube chemistry along with tramp elements required by first article testing. Table 10 shows the mechanical properties obtained in first article testing.

Economic Results

A detailed economic analysis was performed to evaluate the cost of recycling scrap tubes. The details are shown in Appendix B. Basically, the results show that $1267 can be saved by using scrap material to generate a 105mm M68 preform and $2,367 can be saved on the 155mm M185 using scrap material.

Table 9 - CHEMISTRY FOR RECYCLED 155MM M185 TUBE #75-0001

ELEMENT	VENDOR REPORT FOR 175MM TUBE #7459	WATERVLIET ANALYSIS OF 155MM TUBE #75-0001
C	.34	.33
Mn	.45	.50
P	.010	.008
S	.011	.009
Si	.03	.04
Ni	3.24	3.18
Cr	.92	.94
Mo	.66	.60
V	.12	.13
Cu	-	.09
Al	-	.002
Sn	-	>.008
Sb	-	.005

Table 10 - MECHANICAL PROPERTY RESULTS OF FIRST ARTICLE TESTING OF RECYCLED 155MM M185 TUBE #75-0001

LOCATION	C_V (ft-lbs)	Y.S. (KSI)	T.S. (KSI)	El %	R.A. %
Breech Test Disc After H.T.	28.0 27.0	175.5 179.7	189.6 196.5	- -	39.4 41.5
At Fin. Mach. Br.End Loc.	23.0 22.0	179.8 182.0	192.6 192.6	14.3 14.3	42.4 44.6
50" From Fin.Br. End	25.5 24.5	182.9 184.1	192.6 194.1	14.3 15.0	46.6 44.6
104" From Fin. Br.End	23.5 23.5	182.0 182.9	191.5 193.6	14.3 15.7	45.4 47.8
150" From Fin.Br. End	22.0 22.5	179.8 179.8	191.5 190.0	14.3 14.3	42.8 44.9
218" From Fin.Br. End	20.5 20.5	176.8 178.3	189.0 190.0	14.3 14.3	45.4 47.0
At Fin. Mach Muz. End Loc.	20.5 21.5	176.8 179.8	189.0 191.0	14.3 14.3	45.4 42.0
Muzzle Test Disc After H.T.	19.5 21.0	178.5 176.4	189.0 189.9	12.9 14.3	40.2 44.1

CONCLUSIONS

1. Recycling of scrap gun tubes by rotary forging offers no problems in obtaining dimensional requirements as long as the guidelines given in the computer program are followed.

2. The quality of the resulting recycled tube is a direct function of the quality of the original tube; and this is tied directly to the original vendor and melting practice used, i.e., tubes originally produced by older methods (air melts, etc) result in a low percentage of recycled tubes which meet mechanical property requirements. Tubes originally produced by the newer methods (Vacuum Degassing, Vacuum Deoxidizing, Electroslag Refining, etc) result in nearly 100% of the recycled tubes meeting mechanical property requirements.

3. There is a substantial cost savings recognized when tubes of the newer melting practices are used for recycling into smaller gun tubes.

Appendix A - DESCRIPTION OF COMPUTER PROGRAM

The computer program consists of a main program with seven subroutines. The main program reads in all data and contains the looping to calculate all possible combinations of tubes that can be made from a scrap tube. The number of tubes that can be made from a scrap tube is limited to four. The number can be changed to three if it is obvious there is not enough volume to make four tubes from the scrap tube.

Subroutine VOLCK is called from the main program. The subroutine calculates where to cut the scrap tube, checks cross-sectional area reduction, and checks that the outside diameter of the scrap tube is larger than the tube to be made. The volume of the first segment (breech end) of the scrap tube is compared to the volume of the tube it is desired to produce. The volumes of the following segments are then added until the volume of the tube to produce has been exceeded. The program then subtracts one inch from the length of the last segment added and again compares volume. If the volume of the portion of scrap tube is less than the tube to produce, one inch is added to the last segment used on the scrap tube; and this determines where the tube should be cut in order to obtain sufficient volume to forge the tube to produce. The program then begins one inch from the breech end of the scrap tube, calculates the volume and calculates at what length the same volume is obtained along the tube to produce. The cross-sectional areas at these two points are then compared. If the reduction is within the prescribed limits at this point, one inch is added to the scrap tube length, and the process is repeated until either the reduction limits are exceeded or the end of the tube is reached.

A check on mandrel outside diameter and tube inside diameter is made in subroutine DOD which is called from VOLCK. The length is checked in subroutine ALENCK, which is called by VOLCK. If an intermediate preform is required, subroutine CYLRED is called within VOLCK. (The intermediate preform's outside diameter is calculated so that the reduction in area from the smallest cross-sectional area of the recycled tube is 1.1 to 1. The inside diameter is set equal to 5.52 inches. If the reduction from the intermediate preform to the final tube is greater than 5 to 1, the diameter of the intermediate preform is increased.) Subroutine VOLU calculates the volume of the frustrum of a right circular cone. (The tapered section of a gun tube is described by this shape, thus this subroutine is needed for volume calculations.) Subroutine AREA compares the cross-sectional area between the scrap tube and the tube to be made at equal volumes and returns to VOLCK with a value that indicates whether the reduction is too large, within limits, or too small. Finally, subroutine RELEN resets values for the length and outside diameters of a scrap tube after the first series of tube combinations is attempted. This is necessary because the values of length and diameter may be changed within subroutine VOLCK during the volume check.

Appendix B - Economic Analysis

Cost savings were generated by comparing all costs incurred up to preparing a scrap tube into a rotary forge preform with the cost of purchasing a conventional preform. This was done for both the 105mm M68 and the 155mm M185 preforms. The costs for preparing a recycled tube were estimated from a prototype tube routing for the 105mm M68 and from individual machining steps required for the 155mm M185 as no routing was available. The cost areas and hourly rates were based on Watervliet Arsenal rates as of the third quarter of FY 1981. Table 10 shows the estimated savings per preform when 8" M2A2 or 175mm M113A1 tubes are used to produce two 105mm M68's or one 155mm M185 per scrap tube.

COST SAVINGS

RECYCLED PREFORMS VS CONVENTIONAL PREFORMS

105mm M68

RECYCLED PREFORM COST

Demil., Shipping, etc. $200.00

MACHINING - From Routing WTV 28471 4/14/80, Rev. 2

Cost Area	Unit Std.Hrs.	Hourly Rate	Total
1012	10.30	$46.22	$476.07
1018	8.80	46.05	405.24
1040	3.40	58.94	200.40
1066	3.00	39.56	118.68
4010	3.00	28.34	85.02
		TOTAL	$1,485.41

CONVENTIONAL PREFORM COST

Latest Buy (July 80)	$2675.00
Shipping	77.72
	$2752.72

SAVINGS PER PREFORM

[$1,267]

155mm M185

RECYCLED PREFORM COST

Demil., Shipping, Etc. $200.00

MACHINING - Estimated

Cost Area	Unit Std.Hrs.	Hourly Rate	Total
1012	23.20	$46.22	$1072.30
1018	16.00	46.05	736.80
1040	1.05	58.94	61.89
1066	6.00	39.56	237.36
4010	6.00	28.34	170.04
		TOTAL	$2,478.39

CONVENTIONAL PREFORM COST

Latest Buy (Sept 80)	$4700.00
Shipping	145.08
	$4845.08

SAVINGS PER PREFORM

[$2,367]

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