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HOMOGENIZATION OF CRITICAL STEEL CASTINGS

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PROCESS DEVELOPMENT DIVISION

January 1978

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ARMY MATERIALS AND MECHANICS RESEARCH CENTER
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ABSTRACT

Four different types of castings, the composition of which ranged from low alloy to medium alloy steels, were homogenized at temperatures of 2400 F for periods of 32 and 64 hours. After the austenitizing and tempering treatments substantial increases were observed in the ductility and toughness properties. These results indicated that the degree of property improvement was related to the steel composition, the structural condition of the castings prior to homogenization, subsequent heat treatments after homogenization, and required mechanical properties.

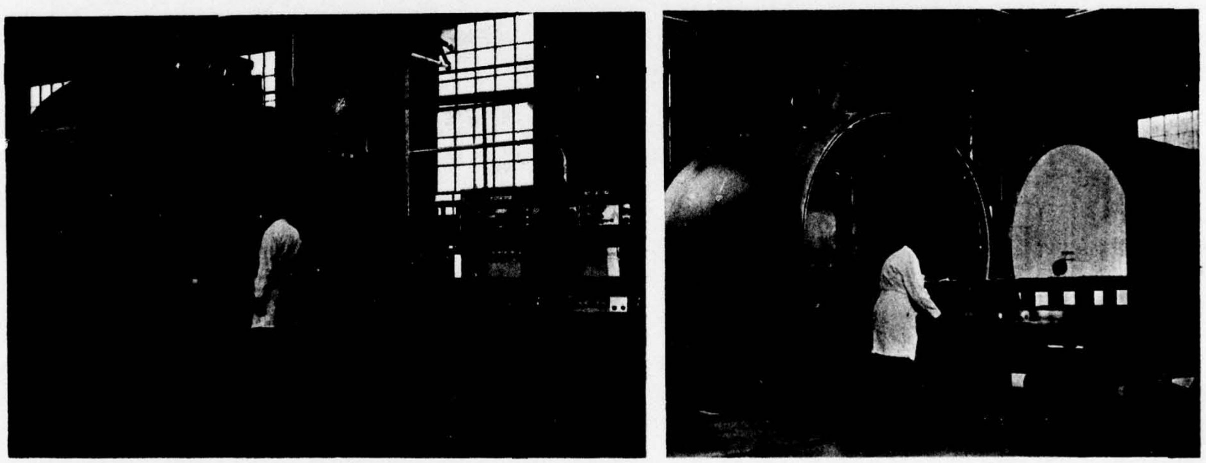
CONTENTS

INTRODUCTION

For many years the Army has had difficulty in the acquisition and reliability performance of certain cast alloy steel components. Some of these components have displayed both nonuniformity and subspecification levels in mechanical properties, i.e., ductility and toughness. These properties are necessary for components to sustain any degree of confidence in their performance during reasonable service. One major cause for this irregularity is alloy microsegregation.

The presence of microsegregation is deleterious at low strength levels but becomes even more undesirable at the higher strength levels. To alleviate this problem the Army has been exploring feasible processing techniques which could improve the quality of critical castings.

Over the past decade, interest in microsegregation in steel castings has led to some constructive investigations[1-4] into dendritic morphology and methods of refinement. The general outcome of these studies has indicated that thermal processing at extremely high temperatures for long periods of time is one method which can be used to eliminate this undesirable situation and consequently improve mechanical properties. Some reluctance by vendors existed in the past to this type of drastic treatment due to the absence of proper high-temperature commercial furnaces and the economics involved in using existing equipment. The recent development of large sophisticated vacuum furnaces such as the one used in this program (see Figure 1) has contributed greatly to the practicability of now considering high-temperature homogenization of steel castings as a feasible process.



19-066-360/AMC-72

Figure 1. High temperature vacuum furnace used in studies.

1. KATTAMIS, T. Z., and FLEMINGS, M. C. *Dendrite Morphology, Microsegregation, and Homogenization of Low-Alloy Steel.* Trans. Met. Soc. AIME, v. 233, 1965, p. 992.
2. THRESH, H., BERGERON, M., WEINBERG, F., and BUHR, R. K. *Microsegregation in Steel Castings.* Trans. Met. Soc. AIME, v. 242, 1968, p. 853.
3. WEINBERG, F., and BUHR, R. K. *Homogenization of a Low-Alloy Steel.* J. Iron Steel Inst., v. 207, 1969, p. 1114.
4. QUIGLEY, F. C., and DeLUCA, E. *Thermal Treatments of High Strength Steel Castings.* First Army Materials Technology Conference, Wentworth-by-the-Sea, Portsmouth, New Hampshire, 1972.

In most of the studies to date the results were obtained from carefully designed test castings produced mainly for R&D investigations. In this program full-scale steel castings of various configurations, dimensions, and alloy compositions were selected to determine the feasibility of utilizing high-temperature homogenization techniques for improving and stabilizing the mechanical properties of commercial components. In their present form and composition these castings barely met required mechanical property specifications. It is anticipated that the results of this program will verify R&D investigations on a commercial scale and offer a significant advance toward establishing a feasible process for upgrading the quality of certain steel castings.

This project was funded as part of the U.S. Army Armament Command Manufacturing Methods and Technology Program.

BACKGROUND

Certain microheterogeneities such as microsegregation, microporosity, and precipitation of interdendritic second phases, resulting during solidification of castings, have significant effects on mechanical properties of cast and wrought steel. These microheterogeneities can usually be controlled or minimized by sound, effective casting practices. Also, further control can be achieved, especially for microsegregation, by subsequent high temperature thermal treatments. Each microheterogeneity has been investigated in detail and the effect on properties established.

Since the substance of this report deals mainly with the effect of homogenization on steel castings, the microheterogeneity mostly affected by this treatment, i.e., microsegregation, will be briefly reviewed.

When steel castings solidify certain variables markedly govern the internal condition of the castings. Factors such as thermal gradients, cooling rates, chemical composition, all have profound influence on the formation of microsegregation usually present to some degree in the internal structure. This phenomenon results primarily from the different rates of diffusion of solute in liquid compared with solid, thus causing alloy concentration gradients within dendritic arms.

In castings which have solidified under nonpreferential heat flow patterns the distribution of some alloy elements, especially nickel and chromium in the interdendritic regions of low-alloy steels, varied substantially around a given dendrite and for different dendrites. However, as observed by some investigators[2,3] the segregation ratio, regions of maximum and minimum concentrations in a specimen, appeared to be independent of position in the casting. The significance of these gradients can be seen by differences in ductility. Once created, these gradients can be altered by high temperature thermal treatments. Alloying elements such as chromium, nickel, manganese, and molybdenum require severe treatments before a worthwhile amount of homogenization will take place. Past commercial homogenizing treatments of a few hours at 2200 F were found to have little or no effect on the distribution of these alloys. However, carbon did diffuse effectively at this temperature.

Results established at M.I.T. and substantiated and used by U.S. Steel[5] indicated long treatments were necessary for complete homogenization of steel alloys containing Ni, Mn, Cr, and Mo. Table 1 lists some times used at 2400 F for sand castings with average secondary dendritic arm spacings ranging from 150 to 300 microns. This range is one usually found in an ordinary sand casting.

Table 1. TEMPERATURES AND TIMES* REQUIRED FOR COMPLETE HOMOGENIZATION

Diffusing Element	Homogenization Time (hr) for 200 μ Casting	300 μ Casting
Ni	29	64
Mn	15	33
Cr	28	63
Mo	27	60

*Calculated from method outlined in Reference 1.

The selection of a homogenizing treatment depends on the condition of the as-cast structure. If the dendritic arms are close together, the concentration gradients are higher and homogenization can be more easily achieved, thus requiring a less severe treatment. Dendrite arm spacing is usually dependent on both cooling rate and alloy analysis but mechanical working in the form of rolling or forging can also affect the arm spacings.

Mathematical models have been developed[1,4] to predict the behavior of the homogenization process in unidirectionally solidified steels containing such principal alloy elements as Ni, Cr, Mn, and Mo. However, the calculated models do not always agree with actual data for commercial castings in which the dendritic structure is the result of omnidirectional solidification but serve only as second- or third-order estimates.

MATERIAL AND EXPERIMENTAL PROCEDURES

Material

The components investigated in this program are illustrated in Figure 2 as follows: (a) drawbar ring coupler (lunette); (b) 155-mm M126 housing; (c) 155-mm XM199 muzzle brake; and (d) 152-mm XM150E5 coupling. These castings were selected for their subspecification qualities.

Chemical Analyses

The chemical analyses of the different types of castings are listed in Table 2. Where discrepancies were present in mechanical properties, chemical analyses were taken on several castings of the same type. These analyses indicated sufficient variance in the carbon content to account for some of the differences in mechanical properties.

5. BIENIOSEK, C. E., SKIDMORE, K. F., and PORTER, L. F. *Undirectionally Solidified Wrought Steel Armor.* United States Steel Corporation, Contract DAAG46-67-C-0158 (X), Final Report. AMMRC CR 69-01 (F) 1969.

a. Drawbar ring coupler (lunette)
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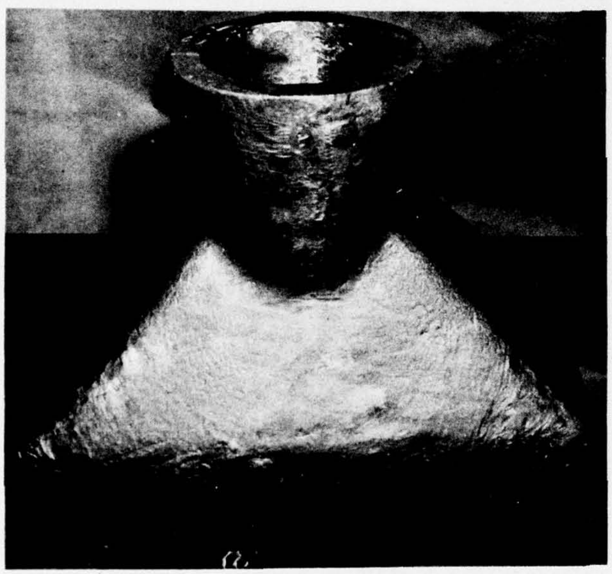
b. 155-mm M126 housing



c. 155-mm XM199 muzzle brake

d. 152-mm XM150E5 coupling

Figure 2. Components used in homogenization studies.

Table 2. CHEMICAL ANALYSES (IN WEIGHT PERCENT) OF HOMOGENIZED COMPONENTS

Components	C	Mn	Si	Ni	Cr	Mo	P	S	V
Lunettes	0.39	1.13	0.62	0.15	0.26	0.12	0.007	0.018	0.06
155-mm Housing (A)	0.29	0.80	0.52	0.46	0.46	0.19	0.029	0.014	-
(B)	0.34	0.86	0.55	0.54	0.56	0.22	0.025	0.010	-
155-mm Muzzle Brake	0.30	0.95	0.33	2.00	0.99	0.45	0.016	0.017	-
152-mm Coupling (A)	0.29	0.73	0.35	2.76	0.85	0.55	0.014	0.010	-
(B)	0.31	0.75	0.31	2.75	0.87	0.52	0.010	0.009	-

Heat Treatment

Half the components were subjected to homogenizing treatments and the results compared to those of castings which were conventionally heat treated. All the castings except the lunettes were homogenized and normalized in a large car bottom vacuum furnace (see Figure 1). The homogenizing treatments consisted of heating castings at 2400 F, followed by normalizing at 1650 F. The conventional austenitizing and tempering treatments were similar to those used by the vendors. In addition, some modified heat treatments were used to further ascertain the effect of homogenization. Four lunettes were homogenized in a smaller vacuum furnace at temperatures of 2300 F and 2400 F followed by a normalize at 1650 F, see Table 3. All lunettes were then austenitized at 1525 F and tempered at 1050 F as prescribed by the vendor.

Table 3. HOMOGENIZATION TREATMENTS

	Treatment	
Lunette	Temperature (F)	Time (hr)
H 1	2300	32
H 2	2400	7-1/2
H 3	2400	15
H 4	2400	27

Test Specimens

Standard 0.252-inch tensile bars and regular 0.394-inch Charpy bars were machined from selected locations of each tested casting. The properties for homogenized versus nonhomogenized castings are listed in Tables 4 through 12.

Metallographic Examination

Macrostructure and microstructure examinations of the castings were conducted before and after homogenization. The specimens were examined in the electron microprobe which revealed the degree of success of the homogenizing treatments. The microprobe technique consisted of subjecting metallographically prepared specimens to an analysis consisting of 50 points per specimen with approximately 50 microns between points. The elements Cr, Mn, and Ni were analyzed.

RESULTS AND DISCUSSION

To explore the practical significance of high-temperature homogenization, actual castings of varying size, complexity, and chemical composition were used in the program. These castings were not consistently within required mechanical property specifications which resulted in considerable casting rejections.

The first component under consideration was the lunette casting, shown in Figure 2a, which was fatiguing and failing occasionally in service. Figure 3 shows a typical lunette failure.

The lunettes were metallographically examined before and after homogenization. An unetched view of the disk cut from the bottom of the shaft of each lunette (see Figure 2a) prior to homogenization revealed undesirable porosity in the form of shrink as shown in Figure 4. The macrostructure revealed dendritic spacings ranging from 180 microns at the edge to 300 microns at the center which is considered quite normal for this type of casting. An electron microprobe of these areas before and after homogenization disclosed chemical segregation, the patterns for which are shown in Figure 5. The manganese, as would be expected, showed greater segregation due to its larger percentage in this steel. The nickel and chromium, which were each around 0.25 percent, were less pronounced. The analysis of the edge disclosed a slightly smaller concentration spread than found in the center of the casting. Slight segregation still existed after the most drastic homogenization treatment of 2400 F at 27 hours, indicating that for complete homogenization longer holding times were necessary.

To determine the effect of homogenization on the mechanical properties, tension and Charpy specimens were machined from the four areas shown in Figure 3. The data are shown in Table 4 and compared with a nonhomogenized lunette. The results show definite increases in yield and tensile strengths and also in Charpy impact values at -40 F, but some decrease in the reduction of area. There was

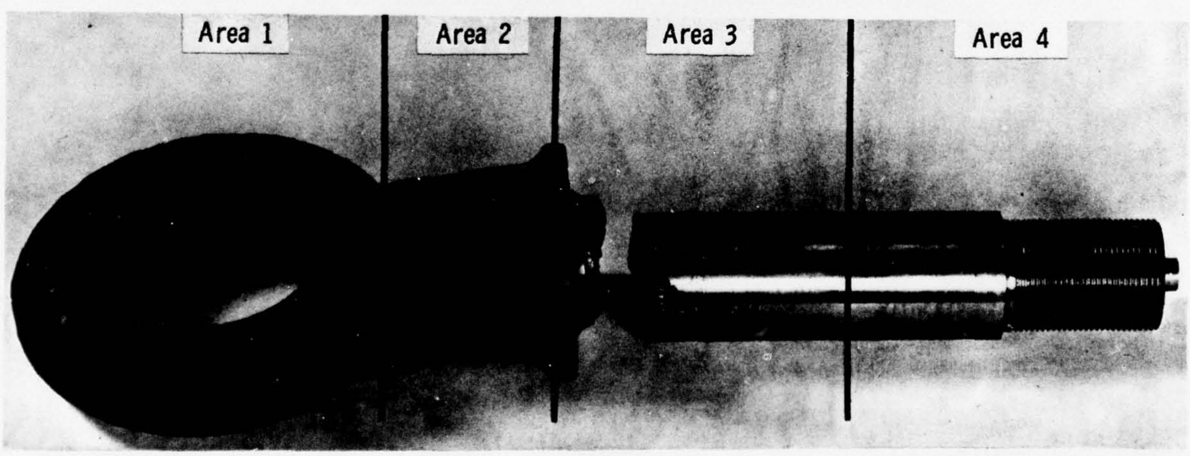


Figure 3. Typical lunette failure.

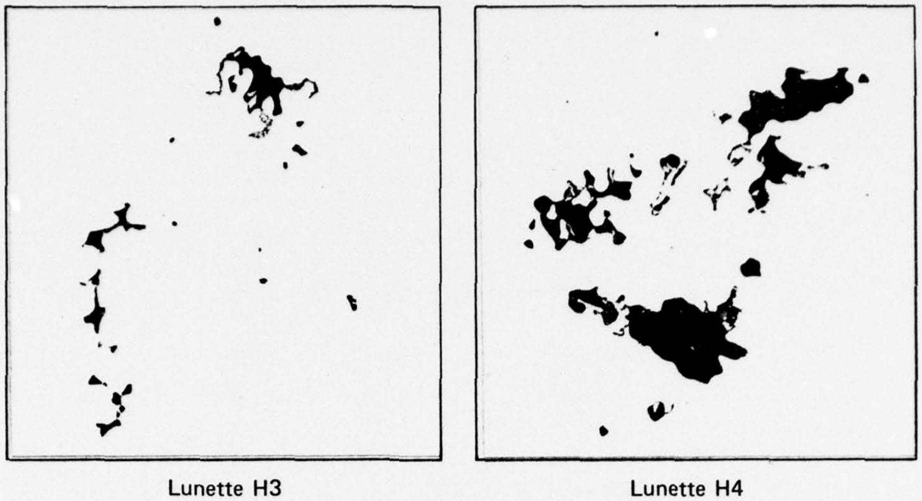


Figure 4. Type of porosity found in lunettes. Mag. 80X

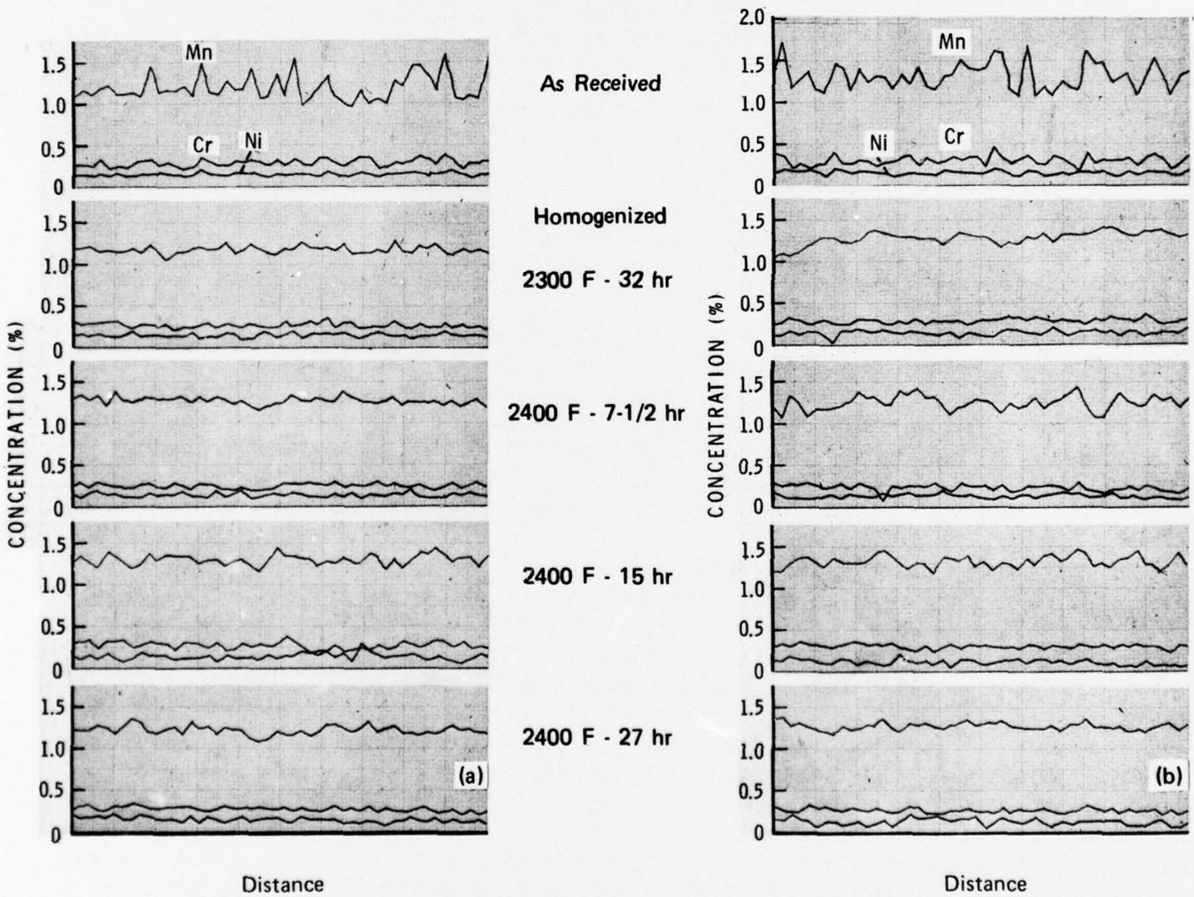


Figure 5. Plotted microprobe analyses of Ni, Cr, and Mn from (a) edge, and (b) center of lunette.

Table 4. MECHANICAL PROPERTIES OF LUNETTES

Specimen	Y.S., 0.2% (psi)	T.S. (psi)	R.A. (%)	Impact Energy, -40 F, (ft-lb)
C1-1	132,250*	142,600	9.9	11.3
2	116,500	136,400	28.8	10.9
3	120,500	140,400	36.0	7.5
4	116,000	137,600	37.2	10.3
H1-1	138,500	147,070	8.0	13.2
2	120,750	139,600	20.8	11.7
3	130,500	148,000	26.0	11.5
4	129,500	146,000	28.8	6.7
H2-1	134,000*	135,000*	10.4*	12.9
2	120,500	140,000	29.4*	11.2
3	129,000†	147,200	18.4	11.8
4	120,000	140,000	26.8	10.0
H3-1	138,500	149,400	14.5	12.1
2	121,250	141,200	27.6	11.7
3	138,000	144,000	9.6	10.3
4	126,000	144,000	26.0	11.5
H4-1	135,500	148,800	27.4	13.7
2	120,250	140,000	15.6	12.4
3	132,000	147,200	14.0	9.7
4	117,000	139,200	17.7	13.0
Requirement	125,000	150,000	22.0	-

*One value
†Outside gage mark
C - only normalized
H1 - homogenized 2300 F - 32 hr + normalized
H2 - homogenized 2400 F - 7-1/2 hr + normalized
H3 - homogenized 2400 F - 15 hr + normalized
H4 - homogenized 2400 F - 27 hr + normalized

no significant change in the results due to the different treatments; however, a definite variation in properties was noticed due to the location from which the test specimens were machined. Area 1 contained the smallest diameter and had the best properties. Area 2, having the greatest mass, was substantially lower. Areas 3 and 4 were the same diameter but Area 3 had a small coupon attached to it (as seen in Figure 2a) which acted as a riser, thus making this area of the casting sounder, with strength properties approaching that of Area 1.

The coupons from the four lunettes were also used in mechanical property determination. Two coupons were homogenized at 2400 F for 15 hours, after which all four were normalized at 1650 F, austenitized at 1525 F, and tempered at 1050 F. Tensile and Charpy bars were machined from coupons which were approximately 1/2" x 1" x 3". The mechanical properties are listed in Table 5. For the same strength level, the RA increased about 34% and the Charpy impact energy about 42% for the homogenized specimens. It is interesting to note that for the same heat treatment, the strength level of the coupons was about 20,000 psi higher than that of the lunettes. Here again, as in the actual casting, the importance of mass on the mechanical properties is evident. The thin coupons had higher strength levels than the thicker diameter castings from which they were cut. It became obvious that this component made from modified 9440 steel composition was not going to meet the desired specifications through its thicker sections even though the properties of the homogenized coupons were acceptable.

Table 5. MECHANICAL PROPERTIES FROM COUPONS (LUNETTES)

Specimen	Y.S., 0.2% (psi)	T.S. (psi)	R.A. (%)	Impact Energy, -40 F, (ft-lb)
1	157,800	168,000	14.7	12.7
2	154,000	168,000	18.4	13.3
3	155,000	164,000	22.6	19.4
4	155,000	164,000	21.8	17.5
Requirement	125,000	150,000	22.0	-

1+2 - only normalized
3+4 - homogenized 2400 F - 15 hr + normalized

These four lunettes, along with four nonhomogenized lunettes, were subjected to a fatigue test to determine if any increase of fatigue characteristics was derived from homogenization. The procedure and results are included in an informal TACOM Report.* The report states that no improvement, due to homogenization, was apparent in the fatigue properties.

Another casting which displayed subspecification levels in mechanical properties was the 155-mm gun housing shown in Figure 2b in semi-machined condition. This component, cast from modified 8630 steel, did not always meet the requirements for 125,000 psi yield strength and 22.0% reduction of area. Four castings were obtained from a commercial supplier, two of which had been heat treated, partially machined, and rejected, and two of which were still in the cast condition.

To confirm the vendor's property results, one of the semi-machined castings was reheat treated using the vendor's heat treatment and sectioned as shown in Figure 6. Tensile and Charpy bars were machined and tested from the sections and the properties are listed in Table 6. Section A of the second semi-machined gun housing was homogenized at 2400 F for 32 hours, normalized, and given the same austenitizing and tempering treatment as the first casting. The results (Table 7) indicate a definite increase in mechanical properties due to the homogenization treatment.

Table 6. MECHANICAL-PROPERTY DATA FROM REJECTED 155-MM GUN HOUSING, NOT HOMOGENIZED

Location	Y.S., 0.2% (psi)	T.S. (psi)	R.A. (%)	Charpy Impact, -40 F, (ft-lb)
1	119,000	142,800	19.8	5.2
2	119,000	142,000	14.0	10.9
3	121,500	146,000	21.8	7.0
4	118,500	143,200	33.4	9.5
5	130,000	150,400	16.2	10.9
6	142,500	155,200	13.5	7.5
7	162,000	164,800	19.2	8.6
8	150,500	163,600	26.8	9.5
9	139,000	156,800	45.8	6.7
10	113,000	140,400	38.6	12.1
11	129,500	150,000	43.4	11.5
12	108,500	136,000	36.0	10.0
Requirement	125,000	-	22.0	-

Table 7. MECHANICAL PROPERTY DATA FROM REJECTED 155-MM GUN HOUSING, HOMOGENIZED

Location	Y.S., 0.2% (psi)	T.S. (psi)	R.A. (%)	Charpy Impact, -40 F, (ft-lb)
1	144,000	156,800	36.6	15.5
2	146,000	158,400	40.4	15.2
3	147,000	156,400	11.0	15.5

*DRISCOLL, G. *Fatigue Testing of Homogenized and Conventionally Heat Treated Lunettes.* TACOM Report 115701 (F), P/N 11625334, MS51337.

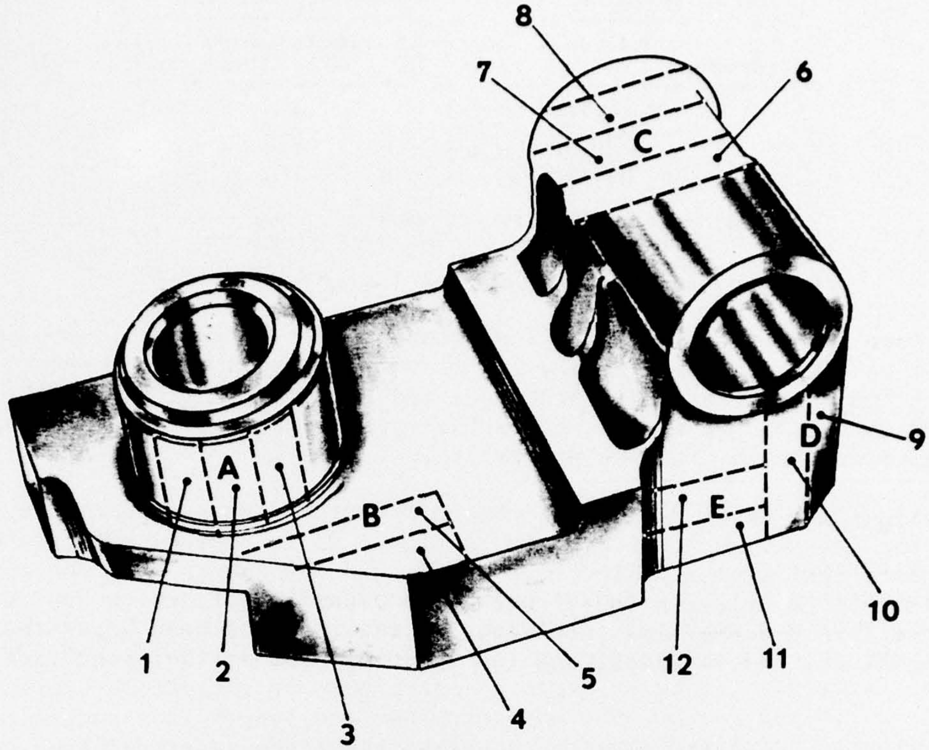


Figure 6. Location of test specimens from 155-mm housing.

Specimens taken from the different areas of the casting, i.e., A,B,C,D,E, revealed the dendritic structures seen in Figure 7. Measurements of the arm spacings ranged from 180 to 450 microns. A microprobe analysis was conducted on section A and the results (Figure 8a) clearly indicated the existence of microsegregation, which probably was one factor for the nonuniformity of mechanical properties. The same area after the 2400 F, 64-hour treatment is seen in Figure 8b. However, the apparent prime reason for the large variance in properties for this steel which has a small hardenability range is the varying thickness dimensions throughout the casting after machining.

A more complete investigation was made of the housing casting. One as-cast housing was cut into quarters as shown in Figure 9. Sections C and D were homogenized at 2400 F, section C for 64 hours, and D for 32 hours. Sections A, C, and D were normalized at 1650 F for 4 hours prior to austenitizing at 1625 F, oil quenching, and double tempering at 950 F.

Tension and Charpy test specimens were machined from each section and tested. The results, listed in Table 8, were more representative of the casting since the thicknesses throughout the as-cast component were still fairly uniform. The data indicated that the only apparent mechanical property improvement due to homogenization was a slight increase in the strength level.

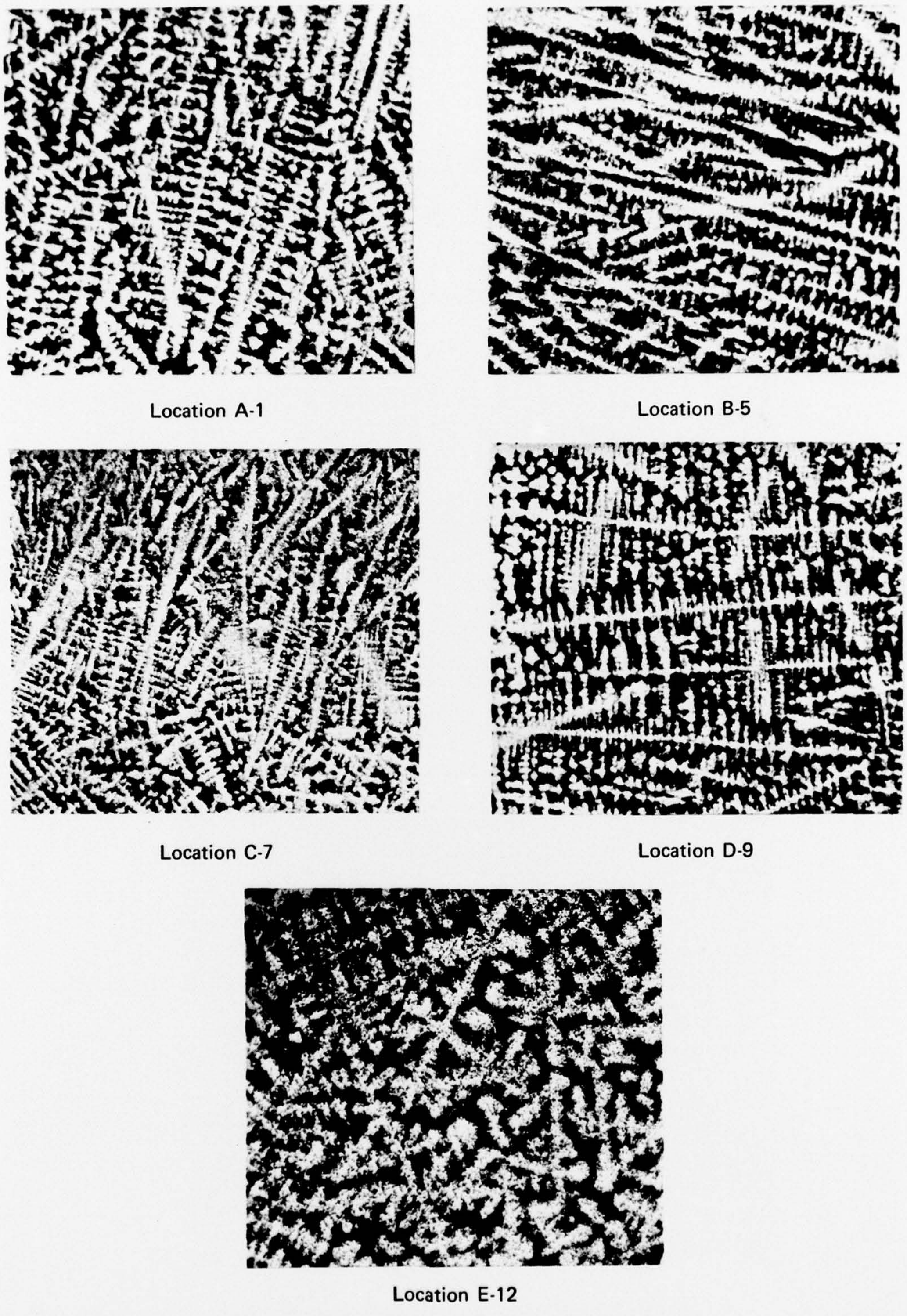


Figure 7. Typical dendritic structures from different areas of 155-mm housing.
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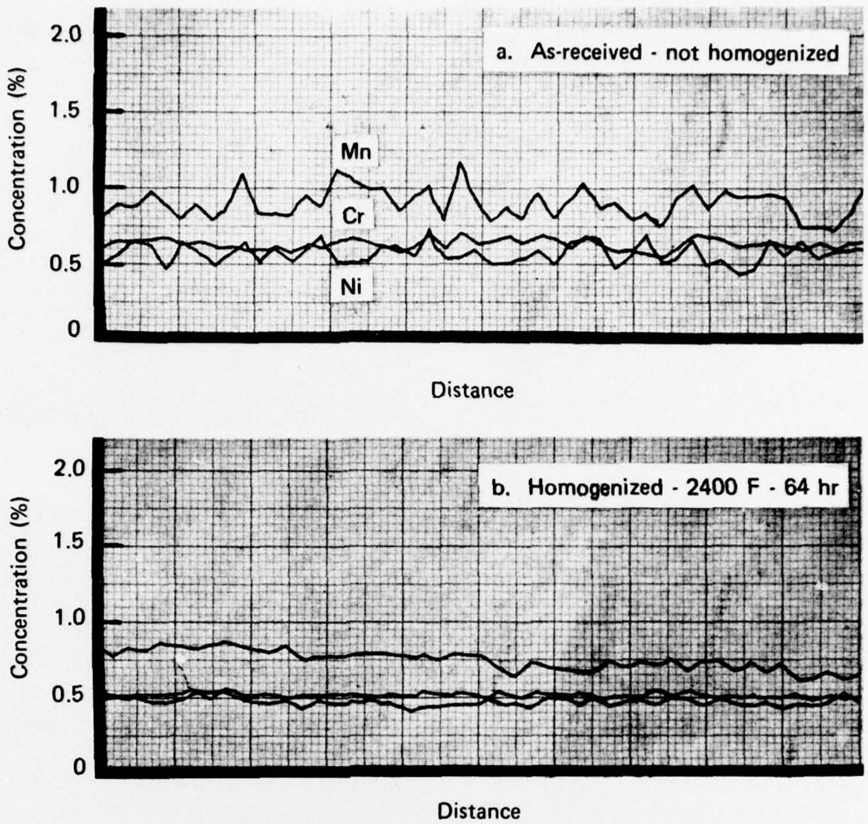

Figure 8. Plotted microprobe analysis results of Ni, Cr, and Mn from 155-mm housing.

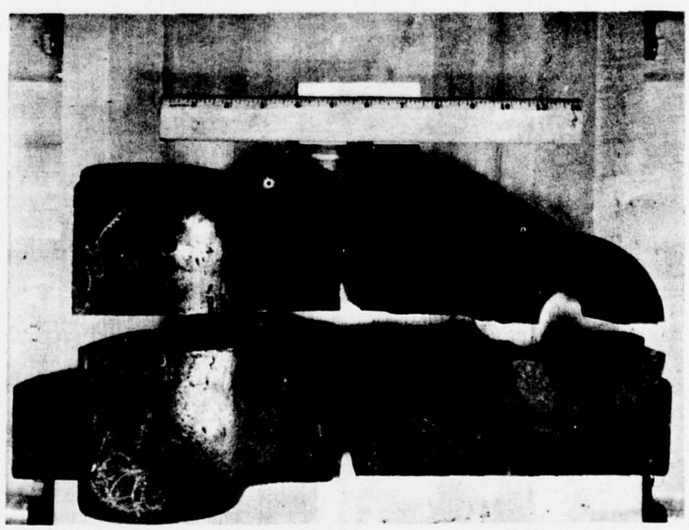

Figure 9. Sectioning of the 155-mm housing prior to homogenization.

The second as-cast housing was sectioned similar to the first and the same homogenization and normalizing treatments used; however, these sections were austenitized at 1550 F and water quenched, followed by the double temper at 950 F. A similar procedure was followed for obtaining tension and Charpy test specimens as was used during the testing of the first as-cast housing. The results listed in Table 9 indicate a substantial increase in the yield strength and Charpy impact values.

The data indicated that in a low alloy steel such as 8630 grade, a homogenization treatment such as those used in this program could be advantageous if better subsequent austenitizing and tempering treatments were used. In this instance, it was obvious that the oil quenching did not produce optimum transformation for good mechanical properties even with the addition of the homogenization treatment. Once the proper quenching medium was used, the value of homogenization was seen in the increased yield strength and Charpy impact properties. Also, it is conceivable that if a higher tempering temperature was used to decrease the higher than necessary yield strength, an increase in the reduction of area could have resulted.

Other components considered in this program which had displayed both nonuniformity and subspecification levels in mechanical properties included the 155-mm muzzle brake and the 152-mm coupling shown in Figure 2c and d.

Similar steps were taken with these components as with the previous castings. Microprobe analyses were conducted to study the amount of microsegregation and also to arrive at a homogenization treatment. Figure 10 shows the results of the microprobe analyses of Mn, Cr, and Ni before and after homogenization. It can be seen that at least 32 hours were necessary for fairly complete homogenization.

Table 8. OIL QUENCHED MECHANICAL PROPERTIES OF 155-MM HOUSING

Specimen	Y.S., 0.2% (psi)	T.S. (psi)	R.A. (%)	Charpy Impact, -40 F, (ft-lb)
A-1*	103,000	126,800	41.6	6.4
2	102,000	125,200	40.4	7.5
3	99,500	124,400	39.2	4.4
4	97,600	122,600	39.1	7.5
5	98,500	123,600	35.4	6.4
C-1†	110,000	133,200	41.0	7.0
2	108,000	132,400	30.2	7.0
3	119,500	139,600	39.8	7.8
4	100,000	122,000	41.6	5.4
5	104,000	127,200	44.6	8.9
D-1‡	119,500	138,400	45.8	7.3
2	108,500	132,000	41.0	5.4
3	113,000	133,600	39.2	8.6
4	113,000	132,800	40.4	4.4
5	111,000	135,600	24.7	8.6
Requirement	125,000	-	22.0	-

*Series A - only normalized
†Series C - homogenized 2400 F - 64 hr + normalized
‡Series D - homogenized 2400 F - 32 hr + normalized

Table 9. WATER QUENCHED MECHANICAL PROPERTIES OF 155-MM HOUSING

Specimen	Y.S., 0.2% (psi)	T.S. (psi)	R.A. (%)	Charpy Impact, -40 F, (ft-lb)
1-1*	130,000	154,000	35.4	5.7
2	123,000	149,600	26.0	9.5
3	125,000	150,400	34.0	7.5
4	118,000	146,800	26.0	7.5
5	121,000	147,200	29.4	9.2
36-1†	153,000	159,200	36.6	18.4
2	153,500	161,600	32.8	17.3
3	151,000	159,600	33.4	17.1
4	150,000	159,200	17.0	15.5
5	142,000	154,000	20.5	15.8
37-1‡	154,000	160,000	32.2	16.8
2	154,000	160,000	21.2	18.1
3	152,750	160,900	23.2	18.4
4	144,850	156,600	28.4	18.4
5	123,000	134,800	30.8	22.2
6	151,000	156,800	35.4	18.4
Requirement	125,000	-	22.0	-

*Series 1 - only normalized
†Series 36 - homogenized 2400 F - 64 hr + normalized
‡Series 37 - homogenized 2400 F - 32 hr + normalized

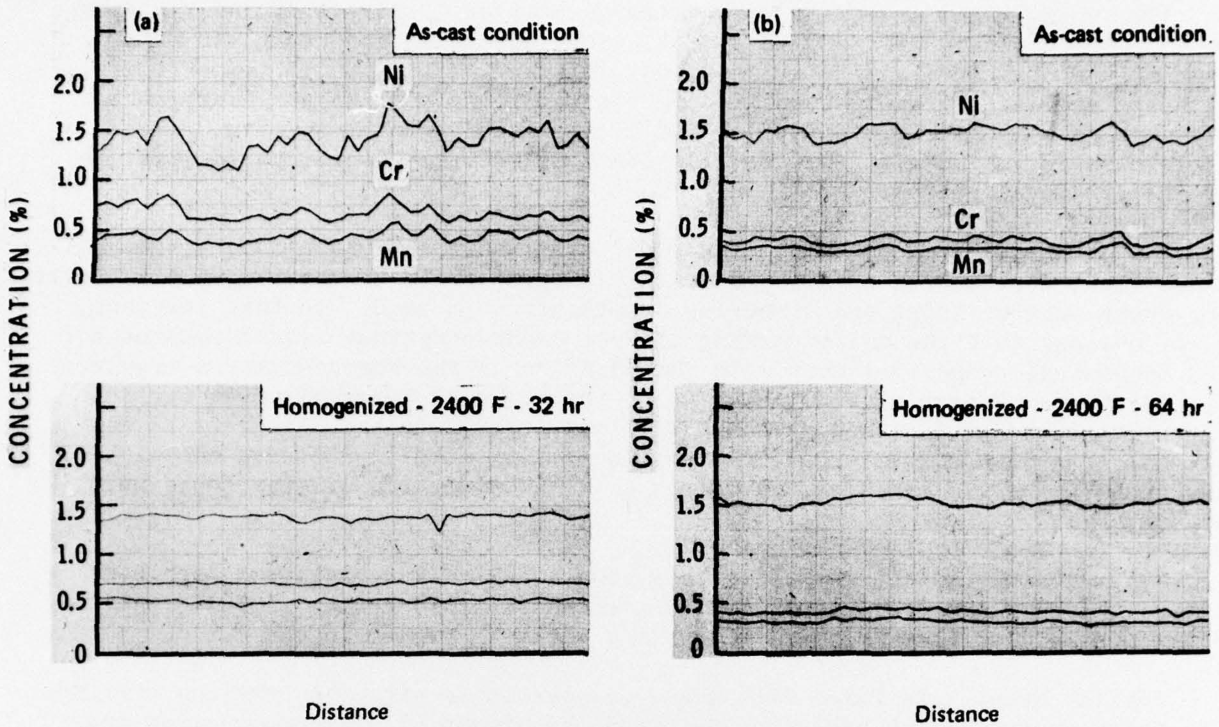

Figure 10. Plotted microprobe analysis results of Ni, Cr, and Mn
(a) 155-mm muzzle brake and (b) 152-mm coupling.

Two couplings, A and B, were used in the program. The chemical compositions of these castings were fairly uniform, as shown in Table 2. Each coupling was longitudinally cut in half. One half of each casting was homogenized at 2400 F, casting designated AH for 64 hours and casting BH for 32 hours. All four sections were then normalized at 1650 F, austenitized at 1550 F, and tempered at 1050 F. Mechanical properties of test specimens taken from each section are listed in Table 10. These results indicated that for coupling A the ductility in terms of reduction of area was below the required 25% necessary for acceptance. However, after homogenization the RA was sufficiently improved to make the casting acceptable. Coupling B, which had a slightly higher carbon content than A and also a higher strength level, had subimpact values and did not meet the 15 foot-pound Charpy impact requirement. After homogenization these requirements were satisfactorily met, making this casting acceptable. Both castings, which would have been rejected, now passed the mechanical property requirements thus saving well over a thousand dollars per casting.

To investigate the potential of homogenization at a higher strength level, test specimens were cut from coupling B in both the nonhomogenized and homogenized conditions. After normalizing all specimens, they were austenitized at 1550 F and tempered at 350 F. The results of tested tensile and Charpy bars are shown in Table 11.

The results for the homogenized section displayed better ductility and toughness at the substantially higher strength level. Here again as with the

Table 10. REPRESENTATIVE MECHANICAL PROPERTIES OF 152-MM COUPLINGS

Specimen	Y.S., 0.2% (psi)	T.S. (psi)	R.A. (%)	Charpy Impact, -40 F, (ft-lb)
A-1*	165,000	179,200	9.6	19.1
2	168,000	182,800	21.2	18.4
3	170,000	184,000	24.7	17.8
4	168,000	183,600	39.8	19.1
5	170,700	183,400	21.0	21.1
AH-1†	177,000	185,500	41.2	23.3
2	174,000	186,400	30.2	21.1
3	171,800	184,700	46.2	21.5
4	172,500	185,450	35.4	22.9
5	173,000	184,800	28.1	21.5
B-1‡	173,000	190,800	34.0	13.6
2	172,100	190,600	42.4	13.0
3	176,000	193,400	41.8	13.3
4	173,000	190,000	20.5	11.5
5	173,000	188,800	39.2	12.1
BH-1**	171,000	186,400	32.8	17.8
2	170,000	186,800	39.2	17.5
3	169,000	184,800	48.0	18.4
4	173,000	186,900	44.0	18.4
5	172,000	188,000	32.2	17.1
Requirement	160,000-190,000	-	25.0	15

*A - only normalized
†AH - homogenized at 2400 F - 64 hr + normalized
‡B - only normalized
**BH - homogenized at 2400 F - 32 hr + normalized

Table 11. MECHANICAL PROPERTIES OF 152-MM COUPLING TEMPERED AT 350 F

Specimen	Y.S., 0.2% (psi)	T.S. (psi)	R.A. (%)	Charpy Impact, -40 F, (ft-lb)
B-1-1*	185,000	258,000	36.6	17.8
2	185,000	254,000	24.0	19.1
3	186,000	254,400	32.0	19.4
BH-1-1†	180,000	248,000	34.0	23.9
2	182,000	250,400	42.8	18.1
3	180,000	249,200	45.8	22.5

*B - only normalized
†BH - homogenized 2400 F - 32 hr + normalized

previous castings, the lunettes and housings, the results seem to indicate that the benefits derived from homogenization are generally more advantageous at the higher strength levels.

The muzzle brakes were processed similar to the couplings. Two castings, C and D, were used, each cut longitudinally in half. Half of each casting was homogenized at 2400 F, section CH for 32 hours and section DH for 64 hours. All four sections were then normalized at 1650 F, austenitized at 1550 F, oil quenched, and tempered at 1150 F. Test specimens were obtained from different areas and results listed in Table 12. Here again, increases were seen in ductility and impact data resulting from the homogenization treatment. For this application the severe thermal treatment was not critical since the low requirements could be met with proper heat treatment. However, once again it is seen that improvements can be made in the mechanical properties, specifically ductility and toughness, by reducing the microsegregation.

OBSERVATION

Plotting the Charpy impact and reduction of area versus yield strength for the tested lunette, housing, and coupling (Figures 11a and b), indicated that

Table 12. REPRESENTATIVE MECHANICAL PROPERTIES OF 155-MM MUZZLE BRAKES

Specimen	Y.S., 0.2% (psi)	T.S. (psi)	R.A. (%)	Charpy Impact, -40 F, (ft-lb)
C-1*	133,000	140,000	36.6	30.6
4	136,000	140,800	41.6	27.6
5	126,000	137,200	34.8	27.2
D-1	128,000	136,000	31.4	36.1
2	128,000	136,400	38.6	38.6
CH-1†	132,000	138,600	19.8	44.9
2	135,500	145,600	55.8	29.8
3	135,000	144,800	21.2	29.8
4	130,000	142,000	32.2	34.9
5	137,000	148,800	55.8	-
DH-1‡	130,000	139,600	49.2	39.4
2	129,500	139,200	34.0	36.1
3	127,500	136,000	53.0	36.9
4	132,500	140,800	53.6	41.5
5	127,000	135,200	29.4	47.0
Requirement	130,000 150,000	-	25	15

*C&D - only normalized
†CH - homogenized at 2400 F - 32 hr + normalized
‡DH - homogenized at 2400 F - 64 hr + normalized

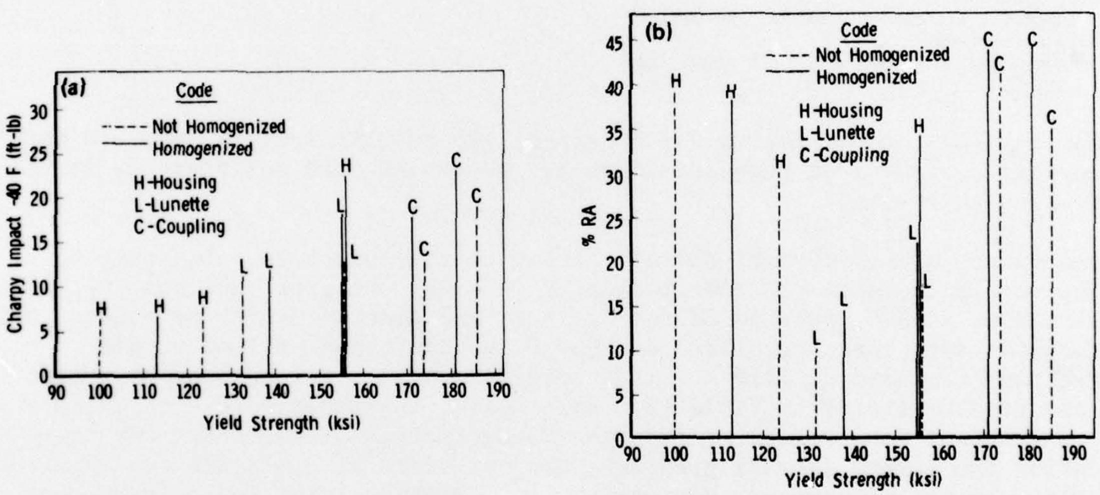

Figure 11. Yield strength versus (a) Charpy impact energy and (b) Reduction of area for investigated castings.

the toughness values were higher for the homogenized castings and, even more dramatic, were further improved at higher strength levels. The ductility, which also showed better results for homogenized castings, was not quite as impressive.

In each instance the vendors attempted to meet the required mechanical property specification by employing thermal treatments which only partially fulfilled the requirements. Although it was not the intent of this program to investigate subsequent thermal treatments, a slightly different heat treatment was employed for some castings after homogenization to compare these results with the conventional results. Also, thinner section sizes were investigated for some of the castings to observe the effect of mass on homogenization.

In the case of the lunettes, it appeared that for the 1-1/2" to 2-1/2" thick mass there was doubt that the specified properties could be obtained under any condition. When one-inch-thick sections were used for the tests, the properties increased to those desired. For the housings the required properties were attained after water quenching. For the coupling, which was made from a better grade of steel, the homogenization treatment was responsible for the increase in the properties that made them acceptable.

All tested components indicated that property improvements can be realized from homogenization, but due to various factors such as steel composition, subsequent heat treatments and required mechanical properties, the conditions which have to prevail to get the maximum benefits are not always the same.

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The author wishes to commend Mr. James Colgate for his constant assistance throughout this program and especially for his interpretation of the raw microprobe data and for presenting it in a useable form. Also, without his full cooperation, patience, and diligence in learning to operate and maintain the car bottom homogenization furnace, the successful completion of the program would have been severely delayed.

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