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METHOD FOR PRODUCING FRAGMENTING STEEL

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ABSTRACT OF THE DISCLOSURE

A method for producing forged steel ordnance device exhibiting improved fragmentation properties attributable to the formation of a brittle and continuous grain boundary network in a steel of hypereutectoid composition or in a hypoeutectoid steel carburized in the hypereutectoid, and methods for making such a device. The device is first heated to the austenite-iron carbide region of the iron-iron carbide equilibrium diagram until carbide precipitation occurs on the austenite grain boundaries, and thereafter the article is quenched to form martensite, and then tempered.

The invention described herein may be manufactured and used by or for the Government for governmental purposes without the payment to me of any royalty thereon.

This invention relates to fragmentation of ordnance articles. More particularly, the invention relates to ordnance articles exhibiting improved fragmentation properties and to a method for improving fragmentation properties of forged steel ordnance articles.

The problem of fragmentation control in ordnance articles such as shells, bombs, grenades and the like is a significant one since it materially affects tactical use and employment and substantially influences technical and economical aspects of production. Existence of the problem has not gone unnoticed and to date several methods of solution have been investigated while others are being considered. These methods are based on controlling the fracture path by such mechanical techniques as machining grooves in the surface of the article or by such metallugrical techniques as using cast iron in which the graphite distribution is determinative of fracture occurrence. While seemingly a solution to fragmentation control is offered by such methods, they are attended by collateral disadvantages, particularly in the area of production and inability to withstand high velocity firing, which tend to offset and mitigate the benefits conferred.

Accordingly, a principal object of the present invention is to provide a method for improving the fragmentation properties of ordnance articles which is unattended by the foregoing disadvantages of the prior art.

Another object of the invention is to provide a method for improving the fragmentation properties of forged steel ordnance articles.

Still another object of the invention is to provide a forged steel ordnance article exhibiting improved fragmentation properties.

Another object of the invention is to provide a forged

ordnance article useable at high velocities exhibiting improved fragmentation properties.

Other objects of the invention will in part be obvious and in part appear hereinafter in the following description of the invention and in the appended claims.

The present invention solves the problem of fragmentation control in ordnance articles, e.g., mortar sheels, by empolying forged steel therein and involves the formation of a relatively brittle grain boundary network by proper heat treatment of such articles. The formation of such network can be accomplished either in a steel initially of hypereutectoid composition or in a hypoeutectoid steel carburized to the hypereutectoid composition. In the latter case, improved fragmentation may be realized even by carburization of a part of the wall of an article to the hypereutectoid composition. Proper heat treatment involves the precipitation of carbide on the austenite grain boundaries by heating in or passing thru at suitable speeds the austenite-iron carbide region of the iron-iron carbide equilibrium diagram, quenching to form martensite from the remaining austenite, and tempering to stabilize the structure and dimensions, reach the desired hardness level and relieve residual stresses.

Articles made in accordance with the disclosed invention exhibit fragmentation comparable to prior art articles made of malleable cast iron and are attended by a better and wider range of mechanical properties. Additional advantages include reduced inspection requirements and shorter heat treating periods. As an economy factor, the latter looms significant when it is considered that the inventive method may require heat treating for a period of about four hours as contrasted with the production of malleable cast iron which necessitates heat treating white cast iron for about 50 hours.

In the course of the investigation leading to the present invention the following experimental procedure was conducted:

EXPERIMENTAL PROCEDURE

Steel cylinders 1" outside diameter with a ⅛" wall and 2½" long were heat treated to obtain a large austenite grain size with ferrite and cementite grain boundaries and a tempered martensite matrix. This martensite matrix was to give the grains the toughest possible structure. The large austentite grains were grown by heating the steel to various high austenitizing temperatures and holding therefor various times.

The ferrite network was obtained by slowly cooling samples of 1045 steel to 1350° F., a temperature at which some of the austenite, particularly that in the grain boundary, transforms to ferrite. Subsequently the steels were oil quenched to transform the remaining austenite to martensite. The martensite was later tempered at 800° F. for one hour.

A carbide network in a hypereutectoid steel was obtained by a heat treatment similar to that which causes a ferrite network in a hypoeutectoid steel. However, as hypereutectoid steels have lower melting points than those containing less carbon, it was necessary to grow large grains, which must be done at high austenitizing temperature, in a 1045 steel and later carburize at a lower temperature.

Cylinders of the same dimension as the steel ones were made of malleable cast iron for tests to compare them with

the steel of various structures. A forged 1045 untreated steel cylinder was also tested for comparsion.

Three cylinders were heat treated simultaneously under any given condition. One was examined metallographically and the other two were fragmented. The fragmentation test consisted of casting Composition B cylinders, ¾" in diameter and 5" long. The charge was then inserted in an assembly consisting of two brass cylinders, 1¾" and ¾" long and of the same inside and outside diameter as the test cylinders, which were placed below and above each iron or steel cylinder respectively in order to eliminate end effects.

This assembly, consisting of the brass and steel tubes and the Composition B cylinder, was placed in sawdust and the explosive initiated with a tetryl pellet. The fragments were collected magnetically and sorted according to size. Representative fragments from each size group of the various steels and cast irons tested were examined microscopically.

characteristics. A partial network, such as possessed by Specimens D–2300–1 and D–2300–4, is considerably less effective and shows only a slight improvement over the forged, untreated steel. Of the two types of intercrystalline networks, the carbide appears to result in better fragmenting characteristics.

Metallographic examinations prior to fragmentation showed that the grain size of the specimens are inhomogeneous and that each piece contained a considerable number of small crystallites.

Microscopic study of the fragments revealed that fracture occurred when network was present practically always along the grain boundaries but not necessarily along each grain boundary.

Fracture due to the hoop stress occurred readily regardless of the network. However, with the possible exception of one cylinder possessing a complete ferrite network, only those samples with a complete or nearly complete carbide network broke into relatively equiaxed fragments

TABLE I.—SUMMARIZED PROPERTIES OF FRACTURE SPECIMENS

Specimen	Steel	Heat treatment	Grain dia. (average), cm.	Grain boundary	Network continuity, percent	Background structure	Hardness No.
D–2100–1	1045	Heated in dry hydrogen at 3,100° F. for 1½ hrs. Cooled slowly in hydrogen to 1,350° F. and held for 1 hr. Quenched in oil. Tempered at 800° F. for an hour.	0.097	Ferrite	10	Tempered martinsete	37.1
D–2250–1	1045	Heated at 2,250° F. in carbon block for 1½ hrs. Transferred in block to furnace at 1,700° F. with RX atmosphere. Cooled to 1,350° F. and held for 1 hr. Quenched in oil and tempered at 800° F. for 1 hr.	0.103	do	10	do	40.1
D–2300–1	1045	Heated at 2,300° F. in dry hydrogen for 1½ hrs. Cooled slowly in hydrogen to 1,350° F. Quenched in oil. Tempered at 800° F. for 1 hr.	0.119	do	20	do	37.6
D–2350–1	1045	Heated at 2,350° F. for 1½ hrs. in carbon block, transferred to furnace at 700° F. with RX atmosphere and cooled at 1,350° F. Held for 2 hrs. Quenched in oil. Tempered at 800° F. for 1 hr.	0.125	do	10	do	43.8
D–2400–1	1045	Heated at 2,400° F. in dry hydrogen for 1 hr. Cooled to 1,350° F. and held for ¼ hr. Oil quenched. Tempered 1 hr. at 800° F.	0.199	do	100	do	29.4
D–2200–3	1045	Heated at 2,200° F. in dry hydrogen for 1½ hrs. Transferred to packed carburizing box at 1,700° F. and held for 21 hrs. Cooled to 1350° F. and held for 1 hr. Quenched in oil and tempered at 800° F. for 1 hr.	0.110	Carbide	10	do	43.5
D–2300–4	1045	Heated in dry hydrogen to 2,300° F. for 2½ hrs. Transferred to carburizing box at 1,700° F. and held for 1½ hrs. Quenched in oil. Tempered at 800° F. for 1 hr.	0.125	do	10	do	47.4
D–1900–1	1045	Packed in carburizing box with carburizing compound-Austinitized at 1,900° F. for 19 hrs. Brought down to 1,350° F. and held for 1 hr. Quenched in oil. Tempered for 1 hr. at 800° F.	0.110	do	95	do	50.6
Z–1	1095	Packed in carburizing box with carburizing compound-Austinitized at 2,200° F. for 1½ hrs. Brought down to 1,400° F. in furnace and held for ½ hr. Quenched in water. Tempered at 500° F. for ½ hr.	0.120	do	100	do	56.1
D–2100–2	1045	Heated at 2,100° F. in dry hydrogen for 1½ hrs. Transferred to packed carburizing box at 1,700° F. and held for 19 hrs. Cooled to 1,350° F. and held for 1 hr. Quenched in oil and tempered for 1 hr. at 800° F.	0.232	do	95	do	42.5

EXPERIMENTAL RESULTS

Table I outlines the various heat treatments and describes the resulting microstructures and hardnesses. It can be noted that steels with complete or nearly complete ferrite and carbide grain-boundary networks and with partial networks were tested. For comparison, cast iron and untreated steel samples were also fragmented. The results of the fragmentation tests are summarized in Table II. (Table in Col. 5.)

DISCUSSION OF RESULTS

The test results show that a complete or nearly complete grain-boundary network improves the fragmentation under the influence of the stresses operating parallel to the cylindrical axis.

Comparison of the steels and cast irons shows that the fragmentation properties of the steels with complete networks are as good as those of the well thought-of cast irons.

Having thus described the invention so that other skilled in the art may be able to understand and practice the same, it is expressly understood that the invention is not limited to the preferred embodiments set forth herein but may be otherwise embodied or practiced within the scope of the appended claims.

TABLE II.—FRAGMENTATION TEST RESULTS

Specimen No.	Average grain diameter, cm.	Network and degree of continuity	R_c	Dust	0–1/2	1/2–2		2–5		5–10		10–20		20–25		25–50		50–75	
						Number	Weight	Number	Weight	Number	Weight	Number	Weight	Number	Weight	Number	Weight	Number	Weight
1045		Untreated	16.9		10.5	68	69	35	110	75	188.5	32	425	8	180.5	15	514.5	3	161.5
D-2100-1	0.097	10% Ferrite	42.5	2	9.5	35	35	21	67	28	189.5	34	494.5	5	110.5	8	582	3	170
				1.5	14	33	33.5	17	56	19	142	17	223	5	112.5	13	496.5	9	582
D-2250-1	0.103	do	40.1	5	18	45	48	37	122.5	14	107	48	661	8	181	16	588.5	1	57
				1	17	47	52	36	118.5	26	186	29	381.5	13	294	19	628.5		
D-2300-1	0.119	30% Ferrite	37.6	20	12.5	47	50	28	109.5	25	178	36	526.5	8	176.5	18	594	1	50.5
				7	27.5	86	81	38	118	28	197.5	25	358	7	158	14	503.5	4	223.5
D-2350-1	0.125	10% Ferrite	43.8	2.5	19.5	57	60	45	152.5	30	199	48	694	10	211.5	10	308.5	1	57
				2.5	6	60	69	37	119.5	51	364	48	446	10	216.5	11	365	1	50.5
D-2400-1	0.199	100% Ferrite	29.4	6	60.5	181	189	108	340	73	519.5	35	441	2	43	20	674.5	3	176.5
				4	10.5	35	34.5	25	83	21	142.5	34	396.5	9	203				
D-2200-3	0.110	10% Carbide	43.5	17.5	84.4	204	98.5	102	335.5	68	487	28	469.5			1	27		
				13		215	111	73	248.5	54	383	35				4	110.5		
D-2300-4	0.125	do	47.5	12.5	34.5	128	119	51	169	43	292.5	46	612	5	111	4			
				30.5	117.5	250	242.5	135	430.5	80	550.5	47	617.5	11	244	6	187		
D-1900-1	0.110	95% Carbide	50.6	121.5		778	730	171	502	12	72.5	23	295.5						
				224		665	622	12	338			2	22						
Z-1	0.120	100% Carbide	56.1	66		801	689.5	113		4		21							
				65.5	296.5	473	478	196	612.5	81	193.5								
D-2100-2	0.232	95% Carbide	42.5	95		684	674.5	146	400	1	5.5	1	10.5						
				115.5		586	583	156	438	19	124.5	3	31.5						
Green		Pearlitic Malleable	54		354	644	620.5	126	354	29	181	2	29						
				56		320	321	160	498.5	45	292	8	97.5						
Red		Pearlitic Malleable	27	31	136.5	335	318.5	197	599	65	413	2	22						
				49.5	180.5	206	193	145	458	74	508.5	21	262.5						
Black		Pearlitic Malleable	15	50	111	203	194	131	416	92	598	27	330						
				60	120														

I claim:

1. A method for improving the fragmentation properties of a forged steel ordnance article by rendering the grain-boundary network thereof substantially continuous, and comprising:
   - heating said article in a temperature range in the austenite-iron carbide region of the iron-iron carbide equilibrium diagram,
   - holding said article in said temperature range until carbide precipitation occurs on the austenite grain boundaries,
   - quenching said article thereafter to form martensite, and
   - tempering the quenched article to stabilize the resultant structure and dimensions and relieve residual stresses, said article being heated to about 2400° F. in dry hydrogen for about 1 hour,
   - cooling said heated article to about 1350° F., and holding at this temperature for about ¼ hour, said cooled article being quenched in oil, and said quenched article being tempered at about 800° F. for about 1 hour, said article yielding a ferrite grain boundary having about 100% network continuity.

2. A method for improving the fragmentation properties of a forged steel ordnance article by rendering the grain-boundary network thereof substantially continuous, and comprising:
   - heating said article in a temperature range in the austenite-iron carbide region of the iron-iron carbide equilibrium diagram,
   - holding said article in said temperature range until carbide precipitation occurs on the austenite grain boundaries,
   - quenching said article thereafter to form martensite,
   - tempering the quenched article to stabilize the resultant structure and dimensions and relieve residual stresses,
   - packing said forged steel ordnance article in a carburizing box with carburizing compound prior to heating said article, said packed article being heated to about 1900° F. for about 19 hours,
   - cooling said heated article to about 1350° F. and holding at this temperature for about 1 hour, said cooled article being quenched in oil, and said quenched article being tempered at about 800° F. for about 1 hour, said article yielding a carbide grain boundary having about 95% network continuity.

3. A method for improving the fragmentation properties of a forged steel ordnance article by rendering the grain-boundary network thereof substantially continuous, and comprising:
   - heating said article in a temperature range in the austenite-iron carbide region of the iron-iron carbide equilibrium diagram,
   - holding said article in said temperature range until carbide precipitation occurs on the austenite grain boundaries,
   - quenching said article thereafter to form martensite,
   - tempering the quenched article to stabilize the resultant structure and dimensions and relieve residual stresses,
   - packing said forged steel ordnance article in a carburizing box with carburizing compound prior to heating said article, said packed article being heated to about 2200° F. for about 1½ hours,
   - cooling said heated article to about 1400° F. and holding at this temperature for about ½ hour, said cooled article being quenched in water, and said quenched article being tempered at about 500° F. for about ½ hour, said article yielding a carbide grain boundary having about 100% network continuity.

4. A method for improving the fragmentation properties of a forged steel ordnance article by rendering the grain-boundary network thereof substantially continuous, and comprising:
   - heating said article in a temperature range in the aus-

tenite-iron carbide region of the iron-iron carbide equilibrium diagram,

holding said article in said temperature range until carbide precipitation occurs on the austenite grain boundaries,

quenching said article thereafter to form martensite,

tempering the quenched article to stabilize the resultant structure and dimensions and relieve residual stresses, said article being heated to about 2100° F. in dry hydrogen for a period of about 1½ hours,

transferring said heated article to a packed carburizing box at about 1700° F. and holding at this temperature for about 19 hours,

cooling said carburized article at about 1350° F. for a period of about 1 hour, said cooled article being quenched in oil, and said quenched article being tempered at about 800° F. for about 1 hour, said article yielding a carbide grain boundary having about 95% network continuity.

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