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GENERAL FEATURES OF THE MANUFACTURE OF CAST ARMOR FOR ARMORED VEHICLES

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WATERTOWN ARSENAL
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WATERTOWN, MASS.

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General Features of the Manufacture of Cast Armor for Armored Vehicles

INTRODUCTION

Cast armor to be used for the armoring of vehicles procured by the Ordnance Department of the Army is purchased on specifications based principally upon the ballistic performance of the material. These ballistic tests are designed to simulate the service expected of castings as incorporated into the structure of the armored vehicle to provide protection for the personnel and machinery of the unit. The ballistic tests cover the following:

1. Resistance to penetration of an armor piercing projectile.

2. Satisfactory exit diameters and condition upon impact with a high velocity projectile which passes completely through the plate.

3. Resistance to shock impact of an overmatching projectile (a projectile whose diameter exceeds the armor thickness and whose striking velocity is controlled so as to deform but not penetrate the plate).

The shape, thickness, and size of armor castings vary considerably. Castings are being produced which range in thickness from 3/8" to 4", and in weight from several pounds to 25,000 pounds, approximately, in some cases. For a given casting, however, the thickness does not vary greatly, and, in general, the larger castings are less intricate than the smaller castings.

Armor castings serve the dual purpose of providing structural strength and protection for the vehicle. Their thickness is governed by the protection demanded, and their shape is controlled by the design of the vehicle from a structural and functional standpoint.

Castings to be used for armored vehicles are made to definite drawings specifying the dimensions, thicknesses of sections and tolerances, and the designed weight of the casting. The Ordnance drawings in conjunction with Specification AXS-492, Ordnance Department, U. S. Army, "Cast Steel Armor" specify the shape and size of the finished castings and the tests to be applied to insure that acceptable quality is being obtained.

QUALIFICATION OF THE CAST ARMOR PRODUCER

The prospective cast armor manufacturer, in order to demonstrate his ability to produce good quality cast armor, is requested to submit test plates as described below to an official proving ground for ballistic tests:

Test Plates Required for Qualification

One test plate, 1" x 18" x 36", for casting thicknesses below 1-1/4".

Two test plates, 1-1/2" x 36" x 36", for casting thicknesses in the range 1-1/4" to 1-3/4".

Two test plates, 2" x 36" x 36", for the thickness range 1-3/4" to 3".

The test plates submitted must be of the composition and with the complete heat treatments that are proposed for use in the production of the armor castings. A manufacturer may qualify for one or all thickness ranges depending upon his production facilities and the size of castings which can be processed.

Once the manufacturer has qualified by meeting the ballistic requirements on the test plates, he is ready to receive orders to produce castings of a definite design and using the chemical composition of steel and the heat treatment upon which qualification is based. Test plates will be cast from each of the several first heats made which are poured into production castings. The test plates will be heat treated and tested ballistically to establish the heat treating cycle and the response to heat treatment of the particular heat of steel. A quality control standard is established by the proving ground agency based upon the ballistic results of the tests on plates cast from a series of heats. After a uniform, satisfactory manufacturing procedure has been established, the number of test plates required for ballistic test may be reduced, at the discretion of the Office, Chief of Ordnance.

If failure occurs on one test plate, the manufacturer has an opportunity to submit two more retests. It is, therefore, good practice for a new manufacturer to cast extra test plates from the first heats of steel which can be held aside until the heat has been accepted. The castings of the heat are required to be given the heat treatment which is successful upon the test plate which meets the requirements.

Occasionally production castings which are amenable to ballistic tests are selected at the discretion of the Ordnance Inspector or higher authority for ballistic tests to insure that the castings are comparable to the test plates in ballistic quality.

CHEMICAL ANALYSIS

The chemical analyses of cast armor are not stipulated by the specifications. The only limitations suggested are that the carbon content does not exceed .30% (to insure weldability of the material) and the nickel, chromium, and molybdenum contents are maintained below certain limits imposed because of the scarcity of these alloys. It is recommended that the nickel, chromium, and molybdenum contents be maintained below .60%. No vanadium additions are allowed because of the extreme scarcity of this element. Silicon contents vary considerably from .30% to approximately 1.0%. The sulphur and phosphorous contents should be kept as low as possible.

The following general types have proven successful:

1. Manganese and low Chromium-Nickel-Molybdenum.
2. Manganese and low Chromium-Nickel-Molybdenum plus 1.0% of Copper.
3. Manganese and low Chromium-Molybdenum.
4. Manganese and low Molybdenum-Copper.
5. Low Chromium-Molybdenum.
6. Silicon-Molybdenum.

It is suggested that compositions similar to the types noted above be considered, the choice to depend upon the experience and preference of the manufacturer. Variations in chemistry, as long as the alloy content is not excessive, are desired in order that superior types may be developed.

A chemical composition should be utilized which is most amenable to the conservation of the alloys being returned to the furnaces as scrap charge. In the case of basic open hearth furnaces it is desirable to keep the chromium contents as low as possible to avoid its loss upon remelting of the scrap charge.

FOUNDRY EQUIPMENT REQUIRED

Melting Equipment

Cast armor up to the present time is produced in basic and acid open hearth furnaces, and basic and acid arc-type electric furnaces.

When acid lined furnaces are used the scrap charge must be carefully controlled to insure that the sulphur and phosphorous contents do not exceed approximately .035%. It has been found that phosphorous contents in the neighborhood of .038-.040% induce brittleness in the material under projectile impact and cracking of the test plates during the shock test often results.

The cleanliness of the steel to be used for cast armor is important, and a good furnace and deoxidation practice are essential. A fine grained steel is generally considered mandatory, and the most common deoxidizer in use is aluminum. This is added in the ladle to the extent of 1 to 2-1/2 pounds per ton of steel depending upon the degree of oxidation of the metal upon tapping. Other deoxidizers which have been used are Calcium-Silicide to the extent of 3 pounds per ton and High Carbon Ferro Titanium in amounts of from 2 to 5 pounds per ton of steel. It is essential, of course, that the steel be "killed" completely in order to obtain sound castings.

In order to obviate variations in results obtained upon heat treatment and to enable the use of a constant heat treatment cycle, it is essential that the chemical composition of successive heats be maintained as closely similar as possible with respect to the important hardening elements. Close control of chemical composition and heat quality will greatly expedite production in the ease of subsequent processing when the procedure has been established.

MOLDING AND CASTING PRACTICE

According to the size and shape, armor castings are being produced in dry sand molds, flame or hot air dried molds, or in green sand molds. The flame or hot air dried molds or the dry sand molds are generally considered preferable. Molds and cores are being produced in the various foundries according to the equipment available and adaptable to the facilities of the shop. Successful molds and cores are being produced by sand slingers, jolters, jolt squeezing and by hand ramming.

Good sand control must be maintained to avoid excessive casting repair and to maintain casting weights as nearly the design weight as possible. All armored vehicles are designed to give a certain performance with a definite weight. Overweight castings may impair the performance of the completed vehicle. Castings are also designed with a minimum thickness which is based upon ballistic protection. The limits imposed by the specification are plus 5% and minus 5% on the designed thickness. It is desirable, therefore, to maintain the thickness of the sections as nearly as possible to the designed values without running under this thickness.

Adequate gating and risers must be provided to insure soundness of the castings, particularly in the critical sections. The critical sections may be indicated on the drawings, and are based upon structural design factors as well as ballistic protection. The yield of finished castings from the furnace product weight seldom exceeds 40-50%.

SOUNDNESS OF CASTINGS

The cast armor producers consider radiographic equipment essential as a tool in determining molding and casting practice. By the use of radiographs a foundry technique can be evolved to produce soundness in the critical areas of the castings and overall soundness as nearly as practicable.

The molding and casting practices are not stipulated. A finished casting, accurate with respect to dimensional tolerances, having a good surface appearance, as sound internally as possible, and of a material having good ballistic properties is required. Without radiographic equipment in the shop or available for use, the laborious method of sectioning the castings must be used to determine whether satisfactory soundness has been achieved.

REMOVAL OF GATES AND RISERS

Castings are prepared for heat treatment by shaking out of the molds at a temperature between 800° and 500°F. The gates and risers are burned off while the castings are still hot to insure that no cracking or heat checks are produced. It is also good practice to insure that the castings do not become cold before they are charged into the homogenising furnace.

HEAT TREATING

The following general heating cycles are considered essential in the heat treatment of armor castings:

1. Homogenize 1850-2000°F. for 6-10 hours. Air cool.
2. Anneal 1100-1250°F. for 4-6 hours. Air cool.
3. Harden 1500-1700°F. for 2-6 hours. Water quench.
4. Temper 1000-1250°F. for 4-10 hours. Air cool.

A. Homogenize

Following removal of the gates and risers the castings are loaded into the homogenizing furnace and slowly heated to the homogenizing temperature. For castings weighing over 50 pounds, the usual type of furnace is a car-bottom furnace, oil or gas fired and with uniform temperature characteristics throughout its chamber. The maximum temperature is used which is compatible with reasonable furnace life. In general, with an increase in homogenizing temperature, the time at temperature required for effective homogenization may be reduced.

The homogenizing cycle is required to give adequate shock properties in the armor at the hardnesses required for satisfactory resistance to penetration. Its effect is to promote diffusion of the segregated elements in the casting resulting from solidification, and produce as nearly as practicable a uniform homogeneous macrostructure free from coarse dendrites and chemical segregation. With the necessity of maintaining alloy as low as possible homogenization also is helpful in imparting greater hardenability to a given chemical composition by dispersing the elements promoting depth hardening homogeneously throughout the section.

More complete homogenization is one of the most effective substitutes for alloy content. It is possible by effective homogenizing to heat treat to a higher physical strength and Brinell hardness in the material thereby achieving superior ballistic resistance without the danger of failures under the ballistic shock test.

B. Sub-Critical Anneal

After homogenization, the castings are cleaned completely by shot blasting before annealing. The annealing operation is performed to soften the castings for removal of the gates and riser stubs and to put the material into a condition for repair welding to r edy surface defects in the castings. The castings are heated in a batch type furnace or a continuous furnace for a sufficient time at 1100-1250° F. to thoroughly soften them. While the castings are still warm in cooling from the anneal, weld repairs may be made. The defect is carefully chipped or ground out and the cavity filled with an electrode material which will develop physical properties comparable to the base material upon subsequent quenching and tempering. A low alloy ferritic electrode is normally utilized.

C. Heating for Quenching and Hardening

The quenching procedure is the most important of the heat treating operations, especially in view of the present necessity of using low alloy chemical compositions. In the first place the castings must be uniformly heated through and to a temperature sufficiencly high that no part of the casting cools below the critical temperature until the casting has been completely immersed in the quenching medium. This necessitates the quenching baths being located in close proximity to the furnaces in order that a minimum of time elapses between the withdrawal of the casting from the furnace and its immersion in the quenching medium. A soaking time of at least one hour per inch of thickness at temperature is considered good practice.

Heating for quenching may be performed in batch type or continuous furnaces. The larger castings are handled individually in order to obtain the maximum possible cooling rate. Large volumes of water, maintained at a temperature between 100 and 140° F. are used with proper agitation of the quenching bath. Caustic or brine quenching baths provide an even more efficient quench and are to be recommended where practicable. Precautions to be taken in heating for quenching and in quenching are as follows:

1. Insure that all parts of each casting are at the proper temperature for quenching.

2. Prevent excessive scale formation or produce a scale which will flake off readily on quenching.

3. Support the casting in the furnace and handle carefully in quenching so as to avoid excessive distortion.

4. Agitate the casting in the quenching medium or provide proper circulation so that steam envelopes are removed and proper quenching takes place.

5. Do not quench cold but retain body heat in the casting to minimize cracking.

D. Tempering

Castings should be tempered as soon as possible after quenching and before becoming cold. It is essential that the castings be held at temperature sufficiently long to insure that a uniform hardness throughout the varying thicknesses of section is achieved. The hardness range established for a lot of castings is comparatively narrow, and is determined by the hardness of the ballistic test plates. The hardness of each casting is checked to insure that it lies within the established hardness range. For a given chemical composition and heat treatment cycle, the Brinell hardness is the best indication of the ballistic properties to be expected of the material and provides assurance to the manufacturer and the Ordnance Department that the proper control has been exercised in quenching and tempering.

WELD REPAIR AFTER FINAL HEAT TREATMENT

Quenching cracks will develop in castings and defects will open up during heat treatment which were not previously detected and which must be repaired. Cracks and other defects must be completely chipped and grooved out to their extreme depths and the grooves filled by arc welded deposits of an austenitic type, such as the modified 18 Cr - 8 Ni electrode. The repaired area is then ground flush and the casting is stress relieved at the tempering temperature or slightly below to soften the adjacent hard and brittle heat-affected zone produced by welding. Proper care and the use of small beads in repair welding may not necessitate subsequent stress relieving depending upon the magnitude of the repair involved. Ferritic electrode deposits may also be used to repair small defects provided a subsequent stress relieving treatment is given the casting.

QUALIFICATION FOR WELD REPAIR

The qualification for major repair welding to be performed before heat treatment consists of filling several pockets or grooves in a standard test plate, heat treating the plate containing the weld repairs and subjecting the plate to a standard ballistic shock test. The procedure thus qualified must be followed in the repair of production castings.

Weld repair of a minor nature after heat treatment does not require qualification, but the procedure used must meet with the approval of the Ordnance Inspector.

WELDABILITY QUALIFICATION OF THE CAST ARMOR MATERIAL

As a test to indicate reasonable weldability of the cast armor for fabrication welding of armored vehicles, a 36" x 36" x 1-1/2" test plate is welded by the armor manufacturer with a double Vee joint down the center. The procedure to be used is not specified, but the electrode specified is modified 18 Cr - 8 Ni; and no preheat or postheat of the armor is allowed. The test plate is then subjected to the standard shock test for the particular thickness of material.

PHYSICAL PROPERTIES AS AN INDICATION OF BALLISTIC BEHAVIOUR

No adequate correlation exists between ballistic characteristics and the physical properties ordinarily measured. There are, however, certain fundamental characteristics which tend to influence ballistic quality. For a given thickness of material there is a definite Brinell hardness range which proves satisfactory and which is in turn dependent upon the type of ballistic test applied. The ballistic test applied is intended to simulate the protection expected from the armor casting in actual service.

For cast armor in thicknesses of 1-1/8" and less, experience has shown that the proper Brinell hardness range is approximately 300-330 Brinell. For greater thicknesses of castings (1-1/4" - 3") the range is 230-270 Brinell.

Within each hardness range ballistic results, especially under the shock test, will be superior with higher ductility in the material as measured by elongation, reduction of area, and Izod impact values.

In order to establish quality control standards and as a manufacturer's check on processing, physical properties are determined on each heat of steel. Separately cast coupons are subjected to the standard heat treatment and test coupons are also cast on the edges of the ballistic test plates. The physical test and Izod impact results thus obtained provide an indication of the uniformity of the process control. When satisfactory control is achieved, the amount of ballistic testing may be reduced without sacrificing quality in castings purchased.

SUMMARY

In summation, the following factors are considered of primary importance in the production of uniform, satisfactory cast armor:

1. Clean heats of steel, properly deoxidized and with close control of chemical composition;

2. Proper foundry practice to produce sound, accurate, and clean castings;

3. Adequate homogenization to provide as uniform a structure as possible;

4. Careful heating for and proper drastic quenching to harden the material throughout its section,

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5) Thorough tempering to produce uniform physical properties throughout the castings. and

6. The maintenance of proper control throughout the processing steps to insure a uniform product.

<u>Note</u>: Copies of this document may be obtained by writing to the Office, Chief of Ordnance, Industrial Service, Tank and Combat Vehicle Division, Washington, D. C.