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HEAT TREATMENT OF ALUMINUM ALLOYS

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This invention relates to the heat treatment of aluminum alloy castings and is particularly concerned with improved heat treating practices for reducing the differential internal residual stresses within castings formed from alloys while simultaneously improving the physical properties of the alloys.

It is therefore the prime object of this invention to provide a new and improved heat treating practice for aluminum alloy castings wherein internal residual stresses are apparently reduced by means of reduction of the differential residual stresses.

This object may be explained further by stating that in complicated castings, that is, castings having varying cross sections and including cavities, etc. therein, made from aluminum alloys, the different cross sections of the casting when treated by the conventional heat treating processes have widely varying residual stresses therein, which variations in residual stresses tend to cause failure of the casting in service. This tendency toward warpage may be explained by the fact that under conventional heat treating practices it is practically impossible to reduce the temperature of the various parts of the castings at equal cooling rates. This unequal cooling in turn sets up differential internal residual stresses within the casting. By utilizing our improved process the effective internal stresses in all sections of the casting are substantially equalized due to the quenching practice, thereby reducing the differential between the internal residual stresses which reduces the tendency toward potential warpage of the casting.

In carrying out the above object, it is another object of the invention to quench castings from a temperature in the neighborhood of 980° F. in oil maintained within a temperature range of from 100 to 175° F. wherein the oil has an S. A. E. motor oil rating of from 30–55. We have found that the temperature, flash point and viscosity of the oil used are all important factors in the success of the process.

A further object of the invention is to provide sufficient oil in the quenching tank to eliminate overheating of the oil during quenching of the castings and to this end it is an object of the invention to provide in the neighborhood of one gallon of oil for each pound in the load being quenched.

A still further object of the invention is to provide a quenching method which reduces the differential between the internal residual stresses of an aluminum alloy casting so that the casting upon age hardening thereof has improved physical properties as well as a reduced tendency toward potential warpage and the like.

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Further objects and advantages will be apparent from the following description wherein preferred embodiments of the invention are disclosed.

Conventional heat treatment methods used in connection with aluminum alloy castings have in the past used a variety of quenching mediums—hot water, cold water, light quenching oil and the like which mediums have all been considered equivalents in the prior art. Aluminum alloy castings, after quenching in one of these mediums, are next subjected to an age hardening process either at room temperature or under accelerated conditions (elevated temperatures) to cause precipitation of the alloying elements held in solution within the casting. These processes of heat treatment have yielded good results in instances where the casting is of a relatively simple shape and of a substantially uniform cross section. In the past few years the use of aluminum alloys in complicated castings has become more prevalent, particularly in the aeronautical industry, wherein motor parts and the like have been cast from aluminum alloys. In such applications, the final horsepower of the motor is often limited by the strength of the aluminum alloy and it has been found that in these high powered engines that there is a tendency for the castings made from aluminum alloys to fail under extreme working conditions; due to internal residual stresses. One of said castings which is particularly difficult to maintain in a substantially unstressed condition is the cylinder head casting. The cylinder head casting for a 12-cylinder V-type motor, for example, weighs in the neighborhood of 100 pounds when made from an alloy, including silicon, copper, magnesium and aluminum. These heads have been tested for warpage by various methods and it has been found that the differential residual stresses are considerable when the heads are quenched in either hot water, cold water or a light quenching oil which has an S. A. E. motor oil rating in the neighborhood of 10, such quenching oil being known to the trade as "S–9 oil."

It is our belief that the stresses in heads quenched by conventional practice are occasioned by the fact that parts of the head having varying cross section cool at different rates and create varying (internal) residual stresses. This may be explained by the fact that the conventional quenching mediums have relatively low boiling

points and are relatively easily vaporized, and since the castings are placed in the quenching tank at a temperature above 900° F., the quenching medium directly at the surface of the casting tends to vaporize. The vapors escape immediately from a flat surface permitting fresh quenching medium to come into contact with the surface. However, in complicated castings there are pockets and indentations which entrap the vaporized quenching medium and prevent escape. This gas or vapor pocket insulates a portion of the casting from the quenching medium which causes slower cooling at that portion whereby a different internal stress is built up than in other portions of the casting which have been cooled at a different rate. This theory is substantiated to a great extent by our experiments and by our improved results obtained when using a special oil and quenching method, as will be explained hereinafter.

Our invention is particularly directed to heat treating methods wherein relatively stable, heavy oils, having an S. A. E. motor oil rating preferably in the range of 30–55, are utilized. These oils are more viscous and stable than the S–9 oil and have considerably higher flash points. Thus when a casting heated in the neighborhood of 980° F. is quenched, the oil due to its higher flash point does not vaporize appreciably and, therefore, continues to contact all parts of the casting whereby a uniform rate of cooling throughout the casting is experienced. This uniform rate of cooling obviously sets up less differential between the internal residual stresses within the casting and, therefore, there is less tendency toward potential warpage of the casting.

We have provided a standard test for determining the differential residual stresses by determining the warpage of cylinder head casting quenched in boiling water which may be termed the "slot-bow" method of test. This test, when applied to cylinder head castings is as follows; a six cylinder head is machined parallel at the opposed top and bottom surfaces thereof and is then slotted transversely eighteen times or three slots per cylinder to a depth of 4½ inches. All tests noted hereinafter were made on cylinder heads slotted identically. The head is next placed upon a face plate and the difference in height is measured with a micrometer gauge at each end and in the middle. A definite bow will be noted wherein the middle of the casting is higher than either end thereof. In this test the alloy used in the cylinder heads was likewise similar in all instances and was of the following constituency:

	Per cent
Silicon	5.00
Copper	1.25
Magnesium	0.50
Titanium and/or chromium	0.20
Iron (as an impurity)	0.50
Remainder aluminum	

While this alloy is preferred in a cylinder head it is to be understood that the process is applicable in the heat treatment of aluminum-silicon alloys in general which alloys may or may not include other elements, such as copper, magnesium, manganese, zinc, chromium, iron, nickel, etc., although the process may be used with success on any aluminum alloy which can normally be water quenched without cracking. Obviously, those alloys which are "not short," that is will crack, should not be heat treated by this method. The

following series of tests show results obtained when using different quenching mediums:

(1) A cylinder head as hereinbefore noted was solution annealed at 980° F. for 12 hours and was then quenched in boiling water. The bow of this head was noted to be ⅛" and was taken as an index of 100% differential residual stress. This particular head had a Brinell hardness of 80. A similarly treated head was then aged at 440° F. for 8 hours whereupon the stress measured by the bow was 70% or .08750" with a Brinell hardness of 86.

(2) A cylinder head was solution annealed at 980° F. for 12 hours and was then quenched in an S. A. E. 30 grade motor oil. In this instance the stress was 60% or .0750" with a Brinell hardness of 80. A similarly treated head was then aged at 440° F. for 8 hours whereupon the stress was 30% or .03750" with a Brinell hardness of 89.

(3) A cylinder head was solution annealed at 980° F. for 12 hours and was then quenched in an S. A. E. 55 grade motor oil. This head showed a stress of 44% or .055". A similarly treated head was then aged at 440° F. for 8 hours whereupon the stress was 30% or .375. The Brinell hardness was 87.

From these figures it is apparent that heads quenched in S. A. E. 30 and the S. A. E. 55 motor oil, and aged at 440° F. have less than one half the differential internal residual stresses than does a similar head quenched in boiling water. It is also interesting to note that the Brinell hardness is between 87 and 89 in heads quenched in the preferred high viscosity oils as against a Brinell hardness of 86 for a head quenched in water. Similarly, it was found that a water quenched head has a tensile strength in the neighborhood of 38,300 pounds per square inch whereas a head quenched in S. A. E. 30 oil has a tensile strength of 39,400 per square inch. Thus, the physical properties of the casting are improved by quenching in the heavy oil while simultaneously the differential between the internal residual stresses is markedly reduced.

The flash point of the quenching oil is of great importance. This figure should be above 350° F. to prevent any substantially vaporization and possible insulating effect. The properties of the S. A. E. 30 and S. A. E. 55 are noted to be as follows:

S. A. E. 30

Flash point	385° F.
Saybolt viscosity	260–310 sec. at 100° F.

S. A. E. 55

Flash point	475° F.
Saybolt viscosity	935–965 sec. at 100° F.

It is our opinion that the higher the flash point and viscosity of the oil the more satisfactory it becomes as a quenching medium. Obviously, if the viscosity is too great production difficulties arise which generally limit the type of oil used. These difficulties are mainly in cleaning of the casting after quenching, and circulation of oil through the cooling system.

Another important feature of our invention resides in the maintenance of a relatively low temperature of the oil during the quenching operation. We have found that the oil should never exceed 175° F. and to this end we provide sufficient oil to limit the rise in temperature thereof when the hot casting is immersed therein. Further, we provide cooling means for circulating the oil and cooling the oil so that the oil is

maintained in the neighborhood of 100–125° F. when the quenching operation is started and does not exceed 175° F. at the finish thereof. We have found that by using, one gallon of oil for each pound of casting that sufficient quenching medium is present to maintain the limits desired. For example, in the operation of quenching cylinder head castings, 30 castings are quenched simultaneously, and weigh 3000 pounds while the carrier therefor weighs in the neighborhood of 1300 pounds, making a total weight of 4300 pounds to be immersed in the quenching tank. For this purpose we provide 4300 to 4500 gallons of oil in order to obtain the best results and maintain the oil at 100–125° F. prior to quenching. After quenching the temperature does not exceed 175°.

So far as we are aware the present invention is the only means of reducing the differential internal residual stresses and maintaining or improving static, physical properties within aluminum alloy castings after heat treatment wherein the casting is of complicated shape and varying cross section. As previously stated, the action during the quenching is entirely different than when using water or light oil since in each of these latter cases the quenching medium is vaporized by heat emanating from the casting, which vapor in the complicated casting is often pocketed whereby an insulating film is formed which prevents continued and equal cooling of the various parts of the casting. By using the specific oils noted herein wherein an S. A. E. motor oil rated from 30–55 is preferred we have provided a quenching medium that does not vaporize appreciably upon immersion of the casting therein. Further, we have provided sufficient oil to maintain temperature well below the flash point thereof. For this reason the oil is in constant contact with the casting and thereby cools the same uniformly for reducing the differential residual internal stresses to less than one half of the stress normally present in castings quenched by conventional practice.

While the embodiments of the present invention as herein disclosed, constitute preferred forms, it is to be understood that other forms might be adopted, all coming within the scope of the claims which follow.

What is claimed is as follows:

1. In a method of heat treating complicated aluminum alloy castings, including silicon, for reducing the differential internal residual stresses within the castings, the steps comprising: solution annealing a complicated shaped aluminum alloy casting, having reentrant angles at the surface thereof which form cavities therein at a temperature in the neighborhood of 980° F. and for a period approximating twelve hours, then

quenching said casting in mineral oil having an S. A. E. rating of between 30 and 55, said oil being maintained at a temperature of between 100° and 175° F. throughout said quenching operation.

2. In a method of heat treating complicated aluminum alloy castings, including silicon, for reducing the differential internal residual stresses within the castings, the steps comprising: solution annealing a complicated shaped aluminum alloy casting, having reentrant angles at the surface thereof which form cavities therein at a temperature in the neighborhood of 980° F. and for a period approximating twelve hours, quenching said casting in mineral oil having an S. A. E. rating of between 30 and 55, said oil being maintained at a temperature of between 100 and 175° F. throughout said quenching operation, and then age hardening said quenched casting at a temperature in the neighborhood of 440° F. for eight hours.

3. In a method of heat treating aluminum alloy castings including cavities at the surface thereof for reducing the differential internal residual stresses therein, comprising: solution annealing an aluminum alloy casting which can normally be quenched without cracking, at a temperature of between 900° and 980° F. for a period sufficient to cause substantially all of the alloying ingredients to go into solid solution, quenching the hot casting in a high flash point mineral oil which falls within the range of S. A. E. motor oils numbered from 30 to 55 and simultaneously maintaining the temperature of said oil between 100° and 175° F. by supplying oil in the ratio of one gallon of oil for each pound material to be quenched therein.

4. In a method of heat treating aluminum alloy castings including cavities at the surface thereof for reducing the differential internal residual stresses therein, comprising: solution annealing an aluminum alloy casting which can normally be quenched without cracking, at a temperature of between 900° and 980° F. for a period sufficient to cause substantially all of the alloying ingredients to go into solid solution, quenching the hot casting in a high flash point mineral oil which falls within the range of S. A. E. motor oils numbered from 30 to 55 and simultaneously maintaining the temperature of said oil between 100° and 175° F. by supplying oil in the ratio of one gallon of oil for each pound of material to be quenched therein, and then age hardening the casting for precipitating the alloying ingredients whereby the physical properties of the alloy will improve and the differential internal residual stresses are substantially reduced.

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