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CASTINGS

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ABSTRACT OF THE DISCLOSURE

Fatigue strength of aluminum or aluminum alloy castings is improved by subjecting them to isostatic pressure at an elevated temperature for a sufficient time to heal micropores.

This invention relates to aluminum or aluminum alloy castings having improved fatigue strength and to a process for providing such castings.

In fabricating different members or shapes of aluminum or aluminum alloys, particularly intricate shapes, casting is almost invariably considered, in those cases where there is any choice, because of cost savings over forging and other methods. However, aluminum or aluminum alloy castings are marked by certain disadvantages which limit their use. One such limitation inherent in such castings as commercially produced is that their fatigue strength is significantly inferior to that of forgings. By way of illustration, a forging is generally considered to exhibit a fatigue strength of 25%, or more, greater than that of a corresponding casting. By fatigue strength, in this description, is meant the stress which can be applied for a predetermined number of cycles without failure. In the aluminum industry it is common to designate as the fatigue strength the stress withstood for five hundred million (5×10^8) cycles without failure.

Accordingly, it is an object of the invention to provide aluminum or aluminum alloy castings having improved fatigue strength, on the order of 25 percent or more.

According to the invention, aluminum or aluminum alloy castings are improved in fatigue strength by subjecting them to a sustained, substantially isostatic, pressure application of at least 3000 p.s.i. at a temperature of at least 600°, preferably at a temperature of 700° to 1000° F. By substantially isostatic pressure is meant substantially equal pressure from every side, analogous to the hydrostatic pressure on a body submerged in a liquid at rest. While the pressure should be at least 3000 p.s.i., a range of 5000 p.s.i. and higher, for example 10,000 to 100,000 p.s.i., is usually preferred. Temperatures slightly higher than those stated are permissible although the temperature should not be so high as to cause melting. Lower temperatures are preferably avoided since a consistent improvement cannot be achieved without substantial difficulty. It can be seen from the foregoing that the invention involves subjecting the casting to temperature and pressure levels which are normally applied to effect substantial metal movement. However, in practicing the invention such metal movement is substantially avoided.

An important feature in practicing the invention is that the isostatic pressure is imposed on the entire casting for a sustained length of time, for example several seconds to 1 hour or longer. This can be contrasted to the situation occurring in a forging operation where a given pressure level usually is not sustained by the entire member and usually is not maintained for any significant duration. In forging, the pressure application is either very brief, as in impact forging, or immediately relieved by metal movement or both. In the practice of the invention, the minimum time period for pressure application

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can be considered as somewhat dependent on the isostatic pressure level, as higher isostatic pressures may be maintained advantageously for shorter lengths of time than lower pressures. Temperature is another related factor, as higher temperatures tend to facilitate the advantageous use of lower pressures, shorter periods of pressure application, or both.

Various means may be employed for applying the isostatic pressure in practicing the invention. The most convenient means are mechanical pressure application, as by dies, and fluid pressure application, as by a gas. In mechanically applying the isostatic pressure, the casting is placed within dies shaped to conform to the casting. Pressure can then be applied by any means such as a hydraulic press. It is important that the dies be so constructed as to substantially prevent any metal flow in the casting, i.e. the casting must be confined so as to substantially prevent any significant movement thereof. Thus conventional forging dies would generally have to be modified somewhat with respect to flash planes, or other provision for metal extruding out of the die cavity, as such would relieve the isostatic pressure by metal movement. Since the isostatic pressure which can be applied mechanically is limited only by the press capacity, rather large isostatic pressures can be applied mechanically. For instance, pressures of 20,000 to 50,000 p.s.i., or even much greater pressures of up to 100,000 p.s.i. or more, can be provided using conventional presses. Because of the isostatic pressures easily achieved in mechanical pressure application, the duration of the application often can be relatively short, for example 15 seconds, or in some cases even less, although to assure consistently good results it is advisable to maintain the pressure application for 15 seconds or more.

In fluid isostatic pressure application, the casting may be placed in a chamber which is pressurized to a level corresponding to the isostatic pressure desired while the casting is maintained at a temperature as herein provided. Because of present economic limitations, the autoclaves, or the like, suitable for such simultaneous temperature and pressure application and large enough to handle commercial castings, are often limited to pressure levels of 20,000 p.s.i. or less. Because these pressures are relatively low within the context of the improved process, the duration of pressure application is lengthened somewhat over that permissible with higher pressures.

Castings subjected to sustained temperature and isostatic pressure application in accordance with the foregoing exhibit improved fatigue strength over like castings not so treated. The improvement observed in both sand and permanent mold castings is generally at least 25 percent, although improvements of 50 to 100 percent, or more, are often realized. This is considered the most significant change in properties over those of the untreated casting. While tensile properties may often be improved to some extent, such is considered incidental in comparison to the pronounced improvement in fatigue strength.

The improved castings retain the basic qualities of a cast internal structure. Micrographs taken before and after pressure applications show that there is no discernible deformation of the grains, and that the castings retain their characteristic random grain size, shape and orientation after isostatic pressure application. The isotropic properties characteristic of a cast internal structure, i.e. generally uniform stress and general corrosion resistance, strength, and other properties, in all directions, are likewise retained.

One difference which is observed in metallographic examination of the improved castings, however, is that microporosity is substantially eliminated in its entirety. It

is generally recognized that aluminum or aluminum alloy casting products will exhibit some degree of microporosity regardless of the care that is taken to avoid such. The improved castings exhibit substantially complete freedom from micropores over 0.0001 inch, in size, a size readily discernible at 500 $\times$ magnification in castings not treated in accordance with the invention. By 0.0001 inch in size is meant that the largest dimension does not exceed this value. We have found that substantially eliminating the micro-pores, in the neighborhood of 0.0001 to 0.001 inch, significantly increases the fatigue strength of aluminum castings. Castings improved in accordance with the invention, having their internal structure derived from subjecting such to the isostatic pressure application described herein, are substantially free from micropores over 0.0001 inch in size, the internal structure otherwise being substantially as cast, and they exhibit markedly improved fatigue strength, by as much as 25% or more. It is believed that the improvement in fatigue strength is related to elimination of microporosity as described, and accordingly the duration for which the temperature and isostatic pressure is sustained should be sufficient to render the casting substantially free from such microporosity.

There is no particular aluminum or aluminum alloy composition limitation to which the invention is confined. It is particularly useful for moderate to high strength aluminum alloys generally employed in the more demanding applications, for instance heat treatable aluminum casting alloys. The temperature and isostatic pressure application does not affect the response of the casting to solution heat treatment. Solution and precipitation or other heat treatments may be employed without loss of the benefit conferred by the practice of the invention. In fact, because the temperature range employed in the isostatic pressure application may approximate that used in solution heat treating, the casting can be quenched immediately after isostatic pressure application so as to retain in solution the alloying constituents dissolved during the thermal exposure. An artificial aging treatment can then follow. Obviously a separate heat treatment can be applied after isostatic pressure application. The casting may be machined at any stage before or after isostatic pressure application. For instance, a rough sand casting may be machined, improved as herein provided, heat treated and then finish machined, if desired.

The following are illustrative examples of the invention.

EXAMPLE 1

A full skirted cast diesel engine piston casting of an aluminum alloy containing, nominally, 4½% copper, 1½% magnesium and 2% nickel was produced in a permanent mold. The piston casting measured about 5½ inches in diameter by 6½ inches in height. A die was constructed to receive the piston casting so that, except for the top surface of the piston head, the piston mated closely with the die cavity. The casting was heated to 850° F. and placed in the die which had been preheated. A flat-faced ram was inserted into the open end of the die so that it could bear against the flat top surface of the piston head. The ram, covering the entire piston head, was very closely fitted with the die cavity so as to minimize any metal leakage between the ram and the die cavity. The ram was pressed into the die by a 500 ton hydraulic press for one-half minute, imposing a pressure of over 47,000 p.s.i. on the piston. This pressure was substantially isostatic, as there was practically no metal movement. Since the die cavity and piston were fitted close, the amount of flash observed at the piston head was practically nil. Micrographs further verified the lack of significant metal movement as there was no discernible grain distortion. The micrographs also indicated complete freedom from any micropores over 0.0001 inch in size. Several such pistons were cut into sections from which R. R. Moore type rotating-beam fatigue specimens were machined. The

R. R. Moore fatigue test and the specimens referred to are well known in the art and are described in the American Society for Testing Materials Special Technical Publication No. 91, "Manual on Fatigue Testing," 1949. Machined tensile specimens were also removed from the pistons. The results of the tensile and fatigue tests are compared with the same tests performed on the pistons in the as-cast condition in Table 1.

TABLE 1

Condition	Fatigue strength, p.s.i., 5 $\times$ 10 ⁵ cycles	Tensile strength, p.s.i.	Yield strength, p.s.i.	Percent El. in 2'
As cast-----	9,000	27,000	26,000	0.7
Improved-----	17,000	33,000	26,000	1.6

It can be seen that the fatigue strength of the improved castings was almost double that of the unimproved castings. Some incidental increase in tensile properties is also evident.

EXAMPLE 2

A partially skirted piston casting having a piston ring insert cast in place in the vicinity of its upper periphery was improved in accordance with the process set forth herein. The band-like ring insert was composed of the well-known Ni-Resist cast iron-nickel alloy often employed for this purpose. With the exception of the ring insert, the general size and alloy composition of the piston were identical to that of the fully skirted piston described in Example 1. A die was provided with a mating ram member as in Example 1. Each casting was heated to 850° F., placed in the heated die and the ram was pressed into the die against the piston head for ½ minute by a 700 ton hydraulic press which imposed a substantially isostatic pressure of approximately 54,000 p.s.i. Fatigue specimens were removed from the wrist pin boss of several pistons treated as just described. The fatigue tests indicated that the cast aluminum alloy portion of the composite piston structure was improved to the same extent as that of pistons made entirely of aluminum alloy as described in Example 1. This is a particularly important embodiment of the invention, since ferrous ring inserts are often included in commercial aluminum pistons, especially where heavily loaded. Prior to this invention the inclusion of such an insert, metallurgically bonded in place, was effected by casting the aluminum piston around the insert, but such pistons were characterized by relatively low fatigue strength, especially in the critical wrist pin boss area. Several schemes evolved for forging the piston around the insert but such results in a bond considerably inferior to the metallurgical bond achieved where the insert is cast in place. A further problem occurs in that the forging operation often imposes excess stresses on the ring member causing it to distort, crack, or worse, fail later in service. The improved pistons retain the advantages of the cast in place insert structure while exhibiting markedly improved fatigue strength previously associated only with forged pistons.

EXAMPLE 3

A cylindrical cast iron permanent mold was used to produce 6 inch diameter by 8 inch long castings of an aluminum alloy containing, nominally, 9% silicon, ½% magnesium and 1.8% copper. From these, 5½ inch diameter by 2½ inch long disc-like specimens were cut and machined. The specimens were heated to 800–850° F. and placed in a closely fitted preheated die. A load of 500 tons was applied for one-half minute by a hydraulic press to the top of each specimen. The specimens were reheated to 980° F. and held at that temperature for 8 hours and then quenched in water at 150° F. followed by artificial aging for 10 hours at 310° F. Fatigue specimens of the type described in Example 1 were prepared from these.

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and from specimens which had not been subjected to the pressure application but which were otherwise identical. The fatigue tests in this instance were conducted at a stress of 20,000 p.s.i. and the comparative specimen life extrapolated to the fatigue strength at 5×10^8 cycles. Again tensile properties were also compared. The results of these tests are listed in Table 2, where it is evident that the improved specimens exhibit an improvement in fatigue strength of 33% over the as-cast material.

TABLE 2

Condition	Log mean fatigue life at 20,000 p.s.i. cycles	Extrapolated fatigue strength, p.s.i., 5×10^8 cycles
As cast.....	460,000	12,000
Improved.....	2,354,700	16,000

Tensile strength, p.s.i.	Yield strength, p.s.i.	Percent El.
46,400	39,000	2.1
47,500	39,800	2.5

EXAMPLE 4

Cast pistons of the same size and composition as set forth in Example 1 were placed in an autoclave and subjected to a helium gas pressure of 15,000 p.s.i. at a temperature of about 900° F. for about 2 hours. The results of R. R. Moore type fatigue tests on specimens removed from the wrist pin bosses of these pistons indicated a log mean fatigue life of 1.5×10^6 cycles at a stress of 20,000 p.s.i. which is extrapolated to indicate a fatigue strength of 15,000 p.s.i. for 5×10^8 cycles. That is, nearly the same improvement was realized whether using mechanical as in Example 1, or fluid isostatic pressure application.

What is claimed is:

1. The method of improving an aluminum or aluminum alloy casting comprising subjecting the casting to a substantially isostatic pressure of at least 3,000 p.s.i. while maintaining said casting at a temperature of at least 600° F. but less than the melting temperature thereof, for a sufficient time to render the casting substantially free from micropores over 0.0001 inch in size, said casting being characterized by substantial increase in fatigue strength over a like casting not subjected to said substantially isostatic pressure application.

2. The method of improving the fatigue strength of an aluminum or aluminum alloy casting comprising subjecting the casting to a substantially isostatic pressure of 10,000 to 100,000 p.s.i. at a temperature of 700° to 1000°

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F. for a sufficient time to render the casting substantially free from micropores over 0.0001 inch in size, said casting being characterized by a substantial increase in fatigue strength over a like casting not subjected to said substantially isostatic pressure application.

3. The method according to claim 1 wherein the substantially isostatic pressure is from 5000 to 20,000 p.s.i., applied by the action of a fluid, and is maintained for at least one hour.

4. The method according to claim 1 wherein the substantially isostatic pressure is from 20,000 to 100,000 p.s.i., applied by dies conforming to the shape of the casting, and is maintained for at least fifteen seconds.

5. An improved aluminum or aluminum alloy casting having a cast internal structure substantially free of micropores over 0.0001 inch in size and derived from subjecting an aluminum or aluminum alloy casting to a substantially isostatic pressure of at least 3000 p.s.i. at a temperature of at least 600° F. but less than the melting temperature thereof for a sufficient time to render said cast internal structure substantially free of said micropores, said aluminum or aluminum alloy casting being characterized by an increase of at least 25 percent in fatigue strength over a like casting not subjected to said substantially isostatic pressure application.

6. An improved aluminum or aluminum alloy casting according to claim 5 which includes a cast in place ferrous portion, metallurgically bonded to the aluminum casting.

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