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CENTRIFUGAL CAST ARTICLE AND METHOD OF MANUFACTURE

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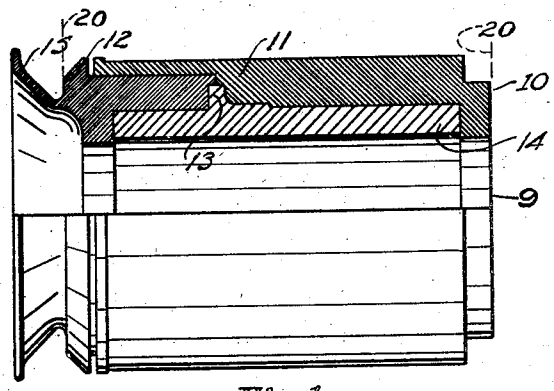


Fig. 1

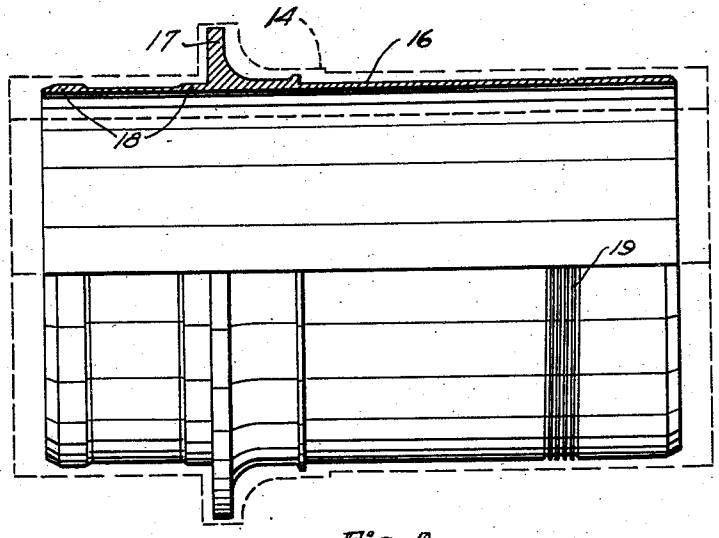


Fig. 2

H. Ford
C. E. Sorenson
R. H. McCarroll

INVENTORS

BY E. C. McRae and Robert J. Harris

ATTORNEYS.

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CENTRIFUGAL CAST ARTICLE AND METHOD OF MANUFACTURE

Henry Ford, Dearborn, Charles E. Sorensen, Detroit, and Russell H. McCarroll, Dearborn, Mich., assignors to Ford Motor Company, Dearborn, Mich., a corporation of Delaware

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1 Claim. (Cl. 309—2)

This invention relates to metal castings and to a method of centrifugal casting therefor.

The class of articles to which this invention has particular reference includes tubular or annular shapes, finished with thin wall sections, and subjected to extreme stresses in use. As a specific example, a cylinder barrel for an air-cooled aircraft engine having a wall thickness of about 125 thousands of an inch will be considered.

The casting method of this invention is particularly designed to replace forging in the manufacture of these articles. However, the same general types of steels now used in forging are used, but a much superior article is obtained. In addition, the process utilizes relatively simple centrifugal casting machines rather than the large and costly installations required for forging.

Essential points of the invention are the control of the cooling rate of the metal during casting and the balancing of the opposing force due to contraction and centrifugal action during the cooling period.

At the present time, cylinder barrels are made by forging, which entails the production of a suitable steel, pouring it in ingots and subjecting it to all the rolling mill operations to form bar stock. This stock is then reheated for the forging process which consists of progressive steps of upsetting and drawing, forming a tubular blank. Thereafter, the forged blank is annealed, the flash is trimmed off and it is brought down to "bullard" size. The blank is rough-machined, heat-treated, finish-machined, and subjected to pickling baths or other surface treatment. In each step the most rigorous care must be exercised to obtain a uniform article.

In contrast, by casting the blank, all the steps incident to rolling the bar stock and the forging operation are avoided. In this period of national and industrial emergency, when steel production and forging facilities are taxed to their utmost, the release of the productive machinery now devoted to the manufacture of this one article alone is of considerable importance.

The advantages are not limited to the economy of production. Even more important is the fact that the finished article is stronger when made by casting rather than by forging, and this is true even though the composition of the metal is identical. And it must be remembered that in aircraft work where every ounce counts and machine elements are stressed to the utmost, any increment in material strength is vital.

The defect inherent in the forged blank arises from the distribution of flow lines in the metal. Inasmuch as forging is essentially a process of extrusion, the dendritic formations and the interstices therebetween are elongated parallel to the axis of extrusion. Even more serious, because of their greater size, are the physical flaws or inclusions which are also extended. These elongated formations form lines along which cleavage may occur under stresses much lower than the metal should withstand normally. In a centrifugal casting, the dendritic formations are radially disposed. As there is no extrusion effect, neither the dendrite, nor the inclusions are extended or enlarged. Further, the dendritic formation, per se, is finer in a centrifugal casting, and while this does not seem to be due to faster cooling alone, if there is some centrifugal effect minimizing size it is not yet fully understood.

Whatever the reason, the structural difference between the forged and cast cylinders is graphically shown under the bursting test. Tubular objects so stressed normally tend to rupture more or less longitudinally since the transverse forces exceed those acting longitudinally. The forged cylinder accentuates this as it almost invariably ruptures on a straight longitudinal line which also corresponds to the zone of weakness established by the extrusion process. In some cases, the rupture appears precisely like a rip or split. Thus, the inherent defect is such that it increases the probability of failure under actual conditions of use. The cast cylinder, however, merely bursts as though punctured despite its tubular shape. These results clearly point the difference between the longitudinal weaknesses of the forging and the over-all uniformity of the casting. It need only be added that the cast cylinder withstands materially higher bursting pressures, as well as exhibiting tensile strengths at least equal to forged steels of the same chemical composition.

However, there have been pronounced limitations on centrifugal casting arising from inability to cast certain steels or to obtain sound castings with the desired microstructure. With the present invention, the same steel may be used in either process and the identical microstructural constituents obtained. Other limitations were the larger number of imperfect blanks obtained and the inability to localize defects in the portion of the blank removed on machining. Each of these has been overcome.

It is, therefore, an object of this invention to obtain an article of the generally described shape, structure and composition which is free from flow lines within the metal. A further object is to evolve a method by which such articles may be produced to a standard economically and quickly.

With these and other objects in view, the invention consists in the arrangement, construction and combination of the various parts of the improved device, as described in the specification, claimed in the claim, and illustrated in the accompanying drawing, in which:

Figure 1 is a quarter sectional view of the mold used in this invention enclosing a cast blank.

Figure 2 is a quarter sectional view on an enlarged scale of a finished cylinder, the outline of the blank from which it was machined being indicated by dotted lines.

As stated, a cylinder barrel has been chosen as a specific example to illustrate this invention, particularly as it embodies the most difficult circumstances of manufacture and use. It will be understood, however, that the method is equally applicable to a wide range of objects, including crankcase rings for radial aircraft engines, tubes for landing gear struts, cylinder liners, bearing races and the like. In each case, the common denominator is the annular or tubular shape and the fact that the relatively thin sections of the finished object are highly stressed.

Referring now to Figure 1, the mold 10 is shown which is made in two parts, 11 and 12, required in the present case because of the circumferential flange 13 on the blank 14, which requires that the mold be separable. In instances where the blank is merely cylindrical, a one-piece mold may be used. The mold 10 is designed to be placed horizontally in a conventional centrifugal casting rotating machine and secured therein. After preheating the mold to a temperature of 450°–600° F., the molten metal at a temperature of approximately 2920° is introduced to the interior through the end 9 while the mold is in rapid rotation. The skirt 15 is provided to protect the mechanism from damage in case of overflow. The molten metal is projected toward the inner circumference of the mold by the centrifugal force and freezes in place in from 50–70 seconds to form a blank 14, as indicated in Figure 1. The mold 10 is removed from the spinning machine, separated in halves and the blank 14 removed therefrom for further processing. The mold, which may be of cast iron or steel, is then sandblasted or washed with a mixture of sodium silicate and silica flour to clean its surface, reheated, and the operation repeated.

In Figure 2, the outline of the blank 14 is shown in dotted line and the finished cylinder barrel 16 is shown with relation thereto to indicate how it is formed from the blank. For the purpose of comparison, and not as a limitation, Figure 2 is shown substantially half the size of a cylinder barrel actually used. From this it will be noted that the wall of the barrel is very thin as compared to the diameter—scaling this drawing indicates this ratio to be about 1 to 40, and thicknesses of this order are representative of most cylinder barrels. It will be noted that it has a circumferential flange 17 and rings 18 by means of which the barrel is secured to the engine crankcase. It also has the threads 19 by means of which a cylinder head is affixed to the barrel. This form of cylinder is, of course, conventional and merely illustrative of one of the types which has been manufactured by this method.

This barrel has heretofore been made by the forging process from bar stock of SAE 4140 steel having the following alloy composition:

	Per cent
Carbon	.35– .45
Manganese	.60– .90
Chromium	.80–1.10
Molybdenum	.15– .25

For the purpose of exact comparison, the centrifugally cast cylinders have been made from the same steel. The following representative test data were obtained:

Heat treatment:
Normalize at 1700°–1750° F.
1550° F. 1 hour—oil quench
1050°–1100° F. 2 hours—draw to 285–321 Brinell

	Forged		Centrifugally cast	
	(1)	(2)	(1)	(2)
Elastic limit.....lbs./sq. in.	122,500	122,000	140,000	142,800
Tensile strength..lbs./sq. in.	140,500	149,500	150,000	153,000
Elongation.....per cent	18	17	14	13
Reduction of area.....do	61.5	59	46.4	43.6
Brinell hardness	285	307	318-321	318-321

It will be noted that the centrifugally cast cylinders have tensile strengths and elastic limits which compare most favorably to those of the forged cylinders. More important in the present instance is that rigorous standards have been set, notably those of the United States Army, for coordination of tensile strength to hardness. The centrifugally cast cylinders excel in that the tensile strength and hardness are co-ordinated within the limits set. Furthermore, other tests on cylinders of corresponding steel to determine the bursting pressure under hydrostatic load show that the cast cylinders are approximately 20 per cent stronger than the forged.

In view of these obvious advantages, the continued use of forging as a method of construction at a time when increased production is imperative and intricate forging machines are not readily available seems rather strange. The explanation, of course, is that heretofore the advantages which should flow from centrifugal casting have not been realized, principally because the casting process itself had not been perfected. To understand these difficulties and the means by which they have been cured, it will be necessary to consider in some detail exactly what occurs during the making of centrifugal castings.

Centrifugal casting has been used for many years in the production of cast-iron pipes and similar objects. It has been used more recently with various steels for producing pipes, gun barrels and other tubular objects, massive in form and relatively thick in section. It has also been used to cast annular articles such as rims, car wheels, and the like. But none of the methods evolved for these types of articles has proved satisfactory when a thin-walled structure able to withstand high stresses is to be obtained.

The reason for this is that as molten metal is poured into the rotating mold, it is chilled on contact with the metal of the mold and tends to solidify. As it solidifies, it must contract while the mold, being heated, tends to expand. At this stage, the casting is far from a solid or hard mass but, rather, may be thought of as being putty-like. The semifluid mass is subjected to two opposing forces; the centrifugal force tends to drive it outwardly into contact with the mold, while the thermal stresses, on cooling, tend to contract it and draw it away from the mold. The result is obvious—the opposing stresses, when they do not cause a complete rupture and failure of the casting, cause a number of small cracks throughout the structure which render the casting worthless.

This condition is a function of the rotating speed of the mold inasmuch as it determines the centrifugal force; and of the cooling effect of the

mold, since it determines the rate of contraction. It might be supposed that if the mold were so constructed that the heat of the metal could be removed practically instantaneously, a sound casting would result, by reason of the shortening of the period during which the metal is semifluid and subject to distortion. It might also be supposed that the speed of rotation could be decreased to lessen the centrifugal force during this period and obtain the same results.

Neither of these suppositions is correct. In the first place, a cold mold does not produce a satisfactory casting and preheating of the mold to about 500° F. is necessary before the metal is introduced. Of course, this temperature level is considerably less than that of the molten metal and also lower than that customarily used; but it has been found that if the metal mass of the mold be increased to increase the speed of cooling, the surface of the casting will be chilled rather than cooled and will be minutely cracked or crazed. Similarly, if the speed is reduced, the molten metal is not subjected to enough force to separate the lighter particles of impurities which must be segregated, after the casting has cooled, adjacent its inner surface. These defects must not be in the portion of the metal which is to form the finished article; and, unless the speed is adequate, these defects will be distributed throughout the body of the metal rather than localized in the inner surface.

Therefore, if a sound and clean casting having a uniform structure is to be obtained, the rotational speed and the cooling rate of the mold must be balanced. This is the essence of this invention insofar as the method is concerned.

It has been discovered that the proper range of peripheral speed is between 1000 and 1750 feet per minute computed on the outer diameter of the casting. It has also been discovered that by the comparatively simple step of proportioning the effective metal mass of the mold to the amount of metal in the casting, a close control over the cooling rate is obtained. The metal of the mold is the primary cooling agent and its thermal capacity directly affects the cooling rate. The term "effective mass" has reference to the portion of the mold readily available for heat transfer—roughly, that included between the projected limits of the casting, as shown between dotted lines 20 in Figure 1. The ratio between the weight of this effective mass and the weight of the casting should be within the range 3 to 4 to 1. In addition, the thickness of the mold wall should preferably be not less than 1½ or 2 times the average wall thickness of the casting.

Another consideration, perhaps as important as the heat capacity of the mold in regulating the cooling rate, is the characteristic of the mold surface as it affects heat transfer. It is essential that this heat transfer characteristic be the same throughout the mold surface. This is true whether the mold be coated, in which case the coating must be evenly applied, or if the mold is cleaned by sandblasting, it must present a uniform surface. There must be no condition on the mold surface which can cause a differential heat transfer at different parts.

When the speed of rotation and the ratio of mold weight to casting weight are maintained within the above ranges and surface conditions permit uniform heat transfer, the proper cooling rate will be obtained and castings will be free from harmful cracking or crazing and from improperly segregated inclusions and defects.

A final requirement as to the formation of the article from the cast blank is that substantially more metal be removed from the inner diameter of the blank than the outer to form the finished article. When this is done, the defects common along the inner diameter, i. e., small inclusions and defects which are forced inwardly by the outward concentration of the heavier metal, are entirely removed. The article will embody only sound, uniform metal of the desired structure.

Three advantages flow from the use of the outer metal. One complete machining operation required with forgings is avoided. The amount of metal in the blank is greatly reduced. The structure of the metal in the outer portion of the blank is best suited to the intended use in that it is more dense, has the least injurious dendritic formation, and generally presents the optimum condition of grain form and arrangement.

Thus, by properly proportioning the mold weight to that of the casting at the ratio of from 3 to 4 to 1, by maintaining the peripheral speed of the mold from 1000–1750 feet per minute, and providing a uniform mold surface, a sound cast blank will be obtained. Then, by utilizing substantially the outer metal in the blank for the finished article and applying the indicated heat treatment, a uniform sorbitic structure is obtained without included matter, cracks or perceptible flow lines.

Summarizing the advantages, an article of superior physical characteristics is obtained. The time for production and the machinery required therefor are greatly reduced. Unifomity of product is increased. The amount of metal required in the process is reduced at least 20 per cent and, in many cases, by as much as 50 per cent. The preheating level, held at approximately 500° F., simplifies production procedure and is also an important step in the cooling rate control. The entire process can be subjected to rigorous laboratory control and much less skill is demanded from the operator. Given metal of the proper composition and temperature which is readily controlled, a casting machine set at an established speed and a mold properly surfaced and preheated, all other variables are eliminated. Uniform production follows as a matter of course.

Some changes may be made in the arrangement, construction and combination of various parts of the improved device and in the steps of the approved method without departing from the spirit of the invention and it is the intention to cover by the claim such changes as may reasonably be included within the scope thereof.

We claim as our invention:

An article of manufacture, a cast steel cylinder sleeve, the wall thickness of which is very small in proportion to the diameter thereof and related thereto in the ratio of substantially 1 to 40, said sleeve being formed of steel having a uniform sorbitic microstructure, the metal thereof being substantially free from extended grain distribution patterns and the dendrites therein being substantially radially disposed.

HENRY FORD.
CHARLES E. SORENSEN.
RUSSELL H. McCARROLL.