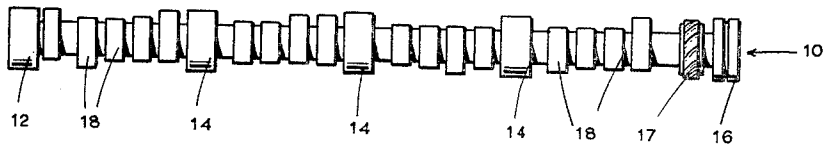
March 24, 1970 E. A. THOMPSON 3,501,976

CAMSHAFT

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FIG. 1



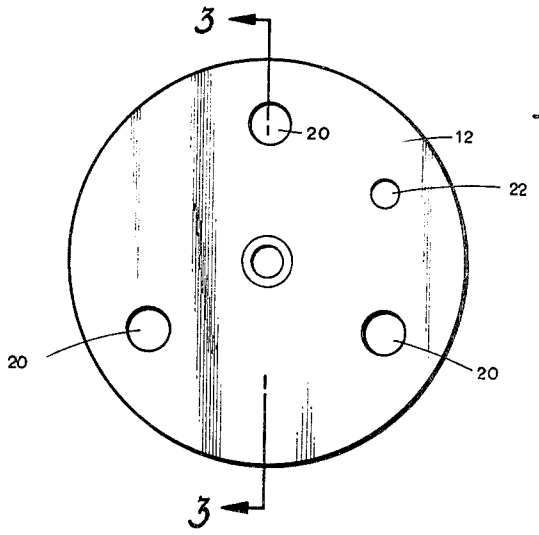


FIG. 2

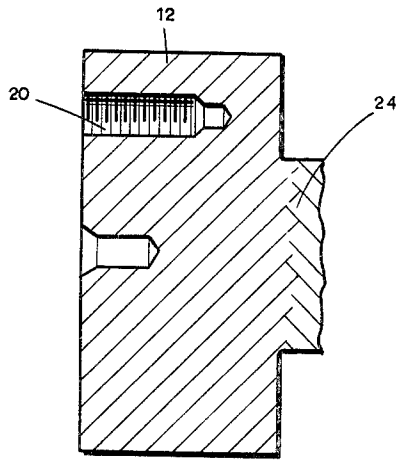


FIG. 3

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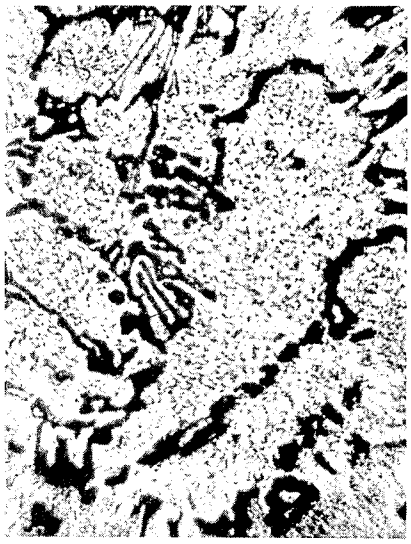


FIG 5 .0001



FIG 7 .0001



FIG 4 .0001



FIG 6 .0001

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United States Patent Office 3,501,976 Patented Mar. 24, 1970

3,501,976

CAMSHAFT

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Filed Feb. 24, 1966, Ser. No. 529,831
Int. Cl. F16h 53/00, 53/02
U.S. Cl. 74—567 4 Claims

ABSTRACT OF THE DISCLOSURE

Camshafts for internal combustion engines are made of a high carbon high chromium alloy containing from about 1.3% to about 3.1% carbon, from about 15% to about 35% chromium with the remainder iron, with or without up to about 3.5% silicon, manganese and other residuals. The alloy is cast, cooled so quickly that a relatively small number of relatively large primary chromium carbide particles are formed and widely dispersed in a matrix of austenite containing a solid solution of chromium and carbon. Then large numbers of relatively small particles of chromium carbides are precipitated from the matrix and distributed throughout the spaces between the large primary carbon particles leaving the remainder of the matrix containing carbon and susceptible to subsequent hardening. Then the casting is hardened by heating and subsequent quenching at such temperature and at such time that the matrix is substantially converted to martensite without significantly changing the carbide particles. The cams may be formed of a metal different from the main body of the shaft, and cast thereon by forming a solid skin over previously poured metal, then remelting the skin to form a single mass of metal by pouring the second metal on the skin.

This invention relates to camshafts for internal combustion engines. It is based in part on my discovery that certain high-carbon, high-chromium iron alloys can be cast and subsequently heat treated to provide a novel metallurgical structure which provides improved camshafts of surprising hardness, durability and dimensional stability.

One of the objects of my invention is to provide an improved camshaft which at one stage of its manufacture is easily machinable and which at a subsequent stage has improved hardness, resistance to wear and corrosion and dimensional stability.

Another object is to provide an improved method of making camshafts in which conventional processes are combined economically to provide an improved camshaft having the qualities mentioned.

Other objects and advantages of the invention will be understood from the following description and claims and from the accompanying drawings, in which

FIG. 1 is a side elevation of a camshaft of conventional shape, to which my invention is applied.

FIG. 2 is an enlarged end elevation, as seen from the left of FIG. 1.

FIG. 3 is a section on the plane designated by the line 3—3 in FIG. 2.

FIG. 4 is a photograph of a portion of a polished and etched section of a casting showing the metallurgical structure of my invention. This photograph is of metal in the condition as cast, and is magnified about 1495 times. The scale line, approximately ⅛ of an inch long at the bottom of the photograph represents one ten thousandth of an inch (.0001).

FIG. 5 is a photograph corresponding to FIG. 4 of the same alloy after a subsequent heat treatment.

FIG. 6 is a photograph corresponding to FIG. 4 of the same metal after subsequent hardening.

FIG. 7 is a photograph corresponding to FIG. 4 of the same metal after drawing following hardening.

Referring to FIG. 1, 10 designates a camshaft of known external shape. This may have journals 12, 14, 16 by which the shaft is supported in the usual bearings, the usual distributor drive gear 17, and cams 18 which operate the usual push rods or rocker arms for actuating the engine valves. The cams must be very hard while other parts of the shaft need not be so hard, and preferably are machinable at some stage of manufacture. For example the gear is preferably machined and front journal 12 customarily has a number of tapped holes 20 by which the driving and timing gear is attached, and a drilled dowel hole 22. This makes problems of manufacture which are solved by my invention.

I cast my improved camshaft of a high-chromium, high-carbon iron alloy. One suitable alloy contains about 2.20% carbon and about 22.5% chromium. This alloy may also contain about 1.60% silicon and about .90% manganese. The silicon may be added to make the alloy easier to pour. The manganese combines with any sulphur which may be present in the material of which the alloy is made. Also the manganese may improve the hardenability of the matrix of the alloy upon quenching. Ordinarily, such alloys are made from available ingredients including scrap or pig iron of uncertain analysis so that the resulting alloy may contain residual quantities of copper, nickel, molybdenum and other metals. As one example an analysis of one batch of my preferred alloy showed 2.20% carbon, 1.60% silicon, .90% manganese, 22.5% chromium, and residuals of .25% copper, .31% nickel and .17% molybdenum.

The silicon, manganese and the residuals amount to about 3.25%, and I believe that these do not importantly affect the final metallurgical structure, for the purposes of my invention. Consequently, alloys containing them come within my definition of an alloy having stated ranges of carbon and chromium, and having the remainder iron.

The camshaft may be cast in any suitable mold which is cooled as explained below. I have discovered that alloys of the composition mentioned above, or of the ranges of composition disclosed herein, can be given a new and improved metallurgical structure by cooling quickly after pouring, and that this new metallurgical structure can be treated to provide new, surprising and very desirable properties. As one example a melt having the proportions of ingredients to provide the alloy of the composition set forth above was poured at about 2750° F. This particular alloy has a liquidus temperature of about 2399° F. and a solidus temperature of about 2270° F., as determined by the Leeds and Northrup carbon determinator.

FIG. 4 is a photograph of a portion of a casting which has been cooled according to my invention. The temperature of this casting has been reduced from the liquidus to the solidus so quickly that two things have happened. One is that the usual formation of primary chromium carbide particles has been arrested, so that the chromium carbide particles formed are fewer in number and smaller than they would be if the metal had cooled slowly. Evidence of this is that the matrix has remained essentially non-magnetic austenite. If the casting had cooled slowly, austenite would not be formed. The other thing that has happened is that the matrix contains large amounts of chromium and carbon in solid solution. Evidence of this is the subsequent formation of very fine chromium carbide particles during subsequent heat treatment. If the casting had cooled slowly the carbon and chromium now remaining in solution would have precipitated out as primary carbides. The primary chromium carbides shown in FIG. 4 are very small, much smaller than if the casting had cooled slowly, also they are more widely dispersed. The largest primary carbide particle visible in FIG. 4, measured in

inches is about .00135 long, and in a representative area .001 square there are about 17 primary carbide particles. The large dark particles shown are what is generally called chromium carbides. Among such chromium carbides Cr_7C_3 and Cr_4C have been identified. It is also possible for iron to replace some of the chromium to form complex or mixed chromium iron carbides such as $(FeCr)_3C$. All of these come within the definition of chromium carbides as that term is generally understood and used herein. The spaces, relatively large with reference to the carbides, are austenite and substantially nonmagnetic. The hardness of the alloy as cast is about 44 Rockwell C.

The metal shown in FIG. 4 was cast in a thin shell mold of silicon sand bound with 3% phenolic resin binder.

The metal was poured at about 2750° F. into molds at room temperature. The thickness of the metal cast and the cooling characteristics of the mold were such that when the casting had cooled below the solidus temperature for this particular alloy, that is about 2270° F. the metallurgical structure shown in FIG. 4, and described above, was formed.

I have found that faster cooling forms even smaller and fewer primary chromium carbide particles. The thickness of the metal influences the rate of cooling and this influences the metallurgical structure and properties of the cast metal, not only as cast, but in subsequent treatment. For example a part of thin cross section such as the main shaft section cools faster than the thick journals. There is an important and discernible difference in the appearance and properties of the metallurgical structures of the two portions as cast. After final hardening, as disclosed below, a thicker cast (slowly cooled) is softer than a thinner casting (quickly cooled). For example a test casting about .190 thick as cast, cooled as described above, will have an ultimate hardness of about 60 Rockwell C, whereas a body having .160 thickness and cooled as described will have a final hardness of about 63 Rockwell C.

I may affect the cooling in other ways. Since a thick section cools more slowly than a thin section it may be necessary to mold thicker sections in zircon sand, for example, which cools the casting faster than silicon sand. Alternatively, chills may be placed in the mold to accelerate the cooling of certain thick parts of a casting, or I may use a permanent mold, water cooled. If the metal cools too slowly the casting will not only be too hard, but it cannot be satisfactorily heat treated so as to be machinable.

The important thing is that the temperature of the metal must be reduced from the liquidus to the solidus so quickly that only relatively small numbers of very small chromium carbides can form, and that they will be formed in an austenite matrix which has large intercarbide spaces in which larger numbers of still smaller chromium carbides can be precipitated upon reheating, while leaving the matrix containing carbon and in a condition which can be hardened. FIG. 4 shows a typical structure, which has properly cooled according to my invention.

After cooling the casting was heat treated as follows. Its temperature was slowly raised from room temperature to about 1600° F. The time required was three hours. It was held at 1600° F. one hour. It was cooled to about 1400° F. during the next 40 minutes. It was cooled to about 1300° F. during the next hour. Total time 5⅔ hours.

FIG. 5 shows a casting after this treatment. It shows that the chromium carbides of FIG. 4 have not changed significantly. The interstices or intercarbide spaces in the previously austenitic matrix are now substantially filled with a dispersion of very small precipitated chromium carbides, having a representative size of the order of about .000018 (18 millionths of an inch). In a representative area .0001 square there are about 13 of these very small particles, or about 1300 particles in the .001 square containing 17 primary carbide particles. Thus although the primary chromium carbides in FIG. 4 are very small (a large one being of the order of a thousandth of an inch long) they are of the order of from 50 to 100 times as large as the smaller carbides formed in the reheating process. The hardness after reheating was from 27 to 33 Rockwell C.

I do not know the exact nature of the matrix after reheating, shown in FIG. 5. It is magnetic. It contains carbon, so that it can be hardened by subsequent heat treatment which appears to convert the matrix essentially to martensite having properties typical of tool steel.

In the foregoing heat treatment the time required is a function of temperature, a lower temperature requiring a longer time. Also the time and temperature of this reheating step influences the amount of carbon left in the matrix and so affects the subsequent hardenability of the alloy, when hardened as disclosed below.

This particular combination of carbide particles and the characters of the matrix in the two conditions appear to make possible the machinability at one stage of my invention and the hardness at a subsequent stage, combined with the surprising dimensional stability and other properties I have observed.

After the foregoing reheating treatment the parts can be machined easily and economically with high speed steel tools and surprisingly the parts can be ground to the exact final shape and desired dimensions. For example the holes **18** and **20** can be drilled, and the holes **18** tapped and the diameters of the journals and the cams are ground to the exact finished size.

Thereafter the shaft may be hardened by holding at a temperature above the critical temperature at which the matrix changes back into austenite and well below the melting point, followed by quenching. The time is a function of temperature, lower temperature requiring longer time. For example the part may be held at about 1750° F. for about twenty minutes, then oil quenched. FIG. 6 shows a casting which has been cooled, then reheated, then hardened as above described. The Rockwell C hardness is about 63 to 65. The two sets of chromium carbide particles have remained unchanged. The matrix has been essentially converted to martensite.

My invention makes possible grinding before hardening so close to final size that the minimum amount of material need be removed in the final grinding step. In the case of articles which are acceptable within tolerances as large as .0001 (one hundred millionths) of an inch, I can grind to final size before hardening. This is of great advantage in manufacturing.

After hardening, the part may be drawn by holding it at a temperature higher than it will ever work in service, for example of about 3750° F., for about one hour. The hardness drops about 1 point Rockwell C and the structure is as shown in FIG. 7, with the alloy discussed above.

The advantages of the invention are realized while varying the proportion of the ingredients of the alloy within the limits stated herein. For example I may use carbon up to 2.35% and chromium up to 27.00% without significantly changing the characteristics of the alloy from those of the preferred analysis given above, for my purposes.

Increasing the proportion of carbon within certain critical limits tends to increase the final hardness and hence wear resistance of the camshaft. More carbon is required in articles having a thick section, because due to slower cooling, more carbon is combined with chromium, which has a very high affinity for carbon. If more carbon were not used, the matrix would be so depleted that it could not be hardened satisfactorily. More carbon than about 2.95% appears to render the article impractically difficult to machine although in some instances I can use up to about 3.10% carbon, particularly with high percentages of chromium, increasing the proportion of chromium within a wider range of critical limits tends to increase the corrosion resistance and reduction of the chromium content below about 15% appears to reduce the corrosion resist-

ance undesirably. Increasing the proportion of chromium beyond about 30% appears to have no important effect on either wear or corrosion resistance, except with very high carbon percentages (above 3.10% for example) and increase of chromium beyond about 35% appears to have no advantage, and may even be undesirable. There is a desirable relationship between the amounts of carbon and chromium to have the desired effects because one part carbon will combine with about ten parts chromium. Therefore higher proportions of chromium require higher percentages of carbon so as to leave in the matrix, after the reheating step, enough carbon not combined with chromium, to harden the matrix satisfactorily in the hardening step discussed above.

For example with my preferred alloy first mentioned, the processes described appear to leave about 1.10% of carbon in the matrix after the first reheating step (in which the smaller carbide particles are formed). Then when the part is hardened as described, the matrix appears to contain no free carbon and is hardened to have properties resembling those of tool steel or 52100 steel. Measurements of properties of the cast and hardened alloy exceed those of steel. For example, a sample of the preferred alloy, cast and treated as above described showed a transverse bending stress of 693,000 pounds per square inch. From this the modulus of elasticity is calculated at 39,000,000. The modulus for steel is about 29,000,000.

Many of the advantages of the invention are present in a range of carbon between 1.70% and 2.85% while using a range of chromium between 15 and 27%.

In articles having different parts requiring different hardness, I find it of advantage to use an alloy having the general characteristics described above but being ever harder and hence even more wear resistant. In such case I may use a carbon content of about 3.10% and may use this with a chromium content varying between about 30% and about 35%. This provides an extremely hard, wear resistant material. It is difficult to machine by cutting tools, and although it is difficult to grind I have found that by confining this material to the parts on the shaft which need not be machined I can satisfactorily machine the other parts. This is partly due to my improved casting process which permits casting of two different metals within very small tolerances, and confines the extremely hard alloy to parts which need not be machined, making it possible for me to make a camshaft to finished size with a minimum of grinding. It is also due in part to the unusual dimensional stability of the material which makes it possible to grind to close tolerances before the hardening step of the manufacturing process described above, and to finish grind by removal of the minimum amount of material.

An example of such article is disclosed in my patent in Great Britain No. 991,513, published May 12, 1965, the disclosure of which is incorporated herein by reference with the same effect as if quoted completely herein. In such case the hard alloy containing about 3.10% carbon and about 27 to 30% chromium is confined to the portion of the shaft between the journals **12** and **16**. One of the other alloys disclosed, such as that containing 2.2% carbon and 22.5% chromium is cast in the mold to form the journal **12**, and while this is still molten the 3.1% carbon alloy is cast in the same mold to form the main body of the shaft, up to but not including the gear **17**. This is done by the method described in my British patent. Also while the upper surface of the shaft near the gear **17** is still molten the gear **17** and journal **16** are poured into the mold, for example of the 2.2% carbon alloy, in the same manner. After the shaft has cooled, there is a single integral casting having its ends of one metal autogenously joined to the center section at bonding zones **24** as more fully disclosed in the British patent.

After the entire casting has been softened, as described above the end journals and gear may be machined and ground practically to final size, and the cams and center journals can be brought to final size with minimum grinding. Thereafter the entire shaft is hardened and drawn, as explained above.

I have successfully made castings having unusually high resistance to corrosion and wear and having exceptional dimensional stability of the alloys having the following analyses.

	C	Si	Cu	Mn	Cr	Ni	Mo
Example:							
I	2.20	1.60	.25	.90	22.5	.31	.17
II	1.70	.81	.09	.60	15.0	.19	.03
III	2.68	1.34	.13	.95	24.0	.30	.11
IV	2.85	1.47	.13	1.01	27.00	.37	.17
V	3.10	1.76	.59	1.29	25.7	.48	.34

I claim as my invention:

1. A camshaft for an internal combustion engine comprising in combination a shaft having a main portion and having a second portion which requires machining during manufacture, the main portion being cast of one metal and the second portion being cast of another and different metal, the metals being autogenously joined by a connecting zone which has the properties of a connecting zone which has been formed by pouring molten first metal into a mold, then while the main body of the first metal is molten forming on its surface a nonliquid barrier composed of the first metal which prevents the flow of molten metal therethrough, then remelting the barrier by pouring molten second metal onto the barrier to form a single body of molten metal, and then cooling the molten metal to form a casting, the second portion being formed of an iron alloy containing from about 2.2% to about 2.35% carbon and from about 22% to about 27% chromium with the remainder iron, the main portion of the shaft being formed of an alloy containing about 3.10% carbon and about 25% chromium with the rest iron, each of the iron alloys having a minimum hardness of about 61 Rockwell C and having a relatively small number of relatively large primary chromium carbide particles distributed in a matrix of martensite and having a relatively large number of relatively small precipitated chromium carbide particles distributed throughout the matrix between the large primary carbide particles.

2. A camshaft for an internal combustion engine having a main camshaft portion formed of one iron alloy composition and a second portion formed of a second different iron alloy composition for attachment of a driving device, the main portion being cast of an iron alloy containing between about 1.3% and about 3.1% carbon and between about 15% and about 35% chromium with the remainder iron and the second portion being cast of an iron alloy containing between about 1.7% and about 2.85% carbon and between about 15% and about 27% chromium, with the rest iron.

3. A camshaft for an internal combustion engine comprising in combination a shaft having a main portion and having a second portion which requires machining during manufacture, the main portion being cast of one metal and the second portion being cast of another and different metal, the metals being autogenously joined, the second portion being formed of an iron alloy containing from about 2.2% to about 2.35% carbon and from about 22% to about 27% chromium with the remainder iron, the main portion of the shaft being formed of an alloy containing about 3.10% carbon and about 25% chromium with the rest iron, each of the iron alloys having a minimum hardness of about 61 Rockwell C and having a relatively small number of relatively large primary chromium carbide particles distributed in a matrix of martensite and having a relatively large number of relatively small precipitated chromium carbide particles distributed throughout the matrix between the large primary carbide particles.

4. A camshaft for an internal combustion engine comprising in combination a shaft having a main portion and having a second portion which requires machining during

manufacture, the main portion being cast of one metal and the second portion being cast of another and different metal, the metals being autogenously joined by a mixture of the two metals in which mixture the properties of the first metal diminish progressively toward the second metal, and the properties of the second metal progressively diminish toward the first metal, the second portion being formed of an iron alloy containing from about 2.2% to about 2.35% carbon and from about 22% to about 27% chromium with the remainder iron, the main portion of the shaft being formed of an alloy containing about 3.10% carbon and about 25% chromium with the rest iron, each of the iron alloys having a minimum hardness of about 61 Rockwell C and having a relatively small number of relatively large primary chromium carbide particles distributed in a matrix of martensite and having a relatively large number of relatively small precipitated chromium carbide particles distributed throughout the matrix between the large primary carbide particles.

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CHARLES N. LOVELL, Primary Examiner