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[54] **METHOD OF PROVIDING AN INTERMEDIATE STEEL LAYER FOR CHROME PLATING ON ROTOR HOUSINGS**

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[52] **U.S. Cl.** ..... **204/36;** 204/38 B; 204/51; 117/93.PF

[51] **Int. Cl.** **C23b 5/62;** C23b 5/06

[58] **Field of Search** ..... 204/38 B, 29, 51, 36; 117/71 M, 93.1 PF; 75/62, 144

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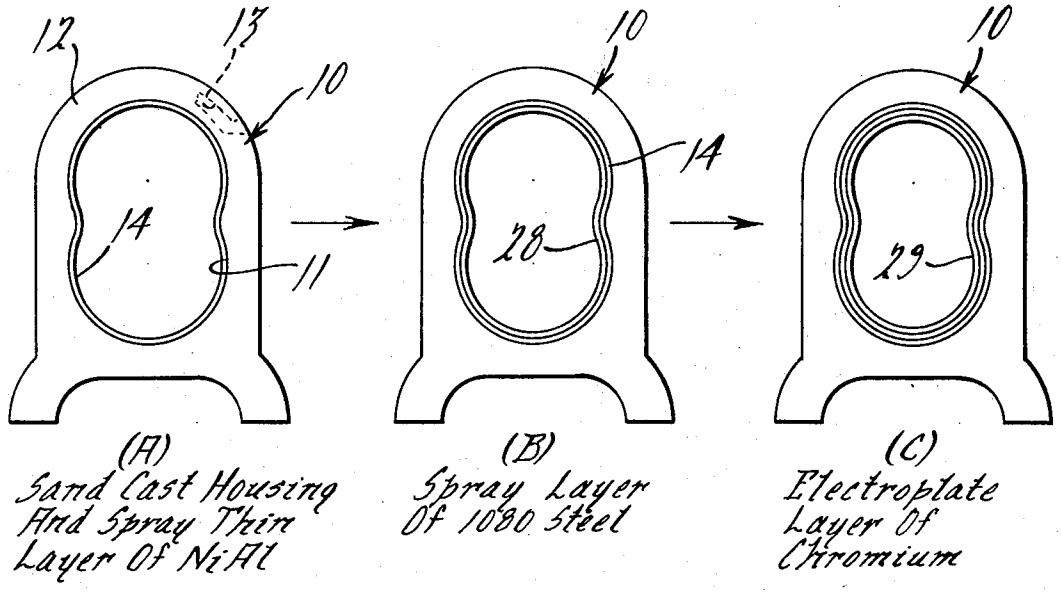
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[57] **ABSTRACT**

A method (and resulting product) is disclosed for making rotor housings useful in a rotary internal combustion engine. The housing is preferably sand cast; the internal epitrochoid surface is flame-spray coated with a thin layer of nickel-aluminide, flame-spray coated with a thicker layer of plain carbon steel, and then plated with chromium. The resulting casting-coating composite provides enhanced wearability, increased dimensional stability, and reduced internal stress of the coatings.

10 Claims, 5 Drawing Figures



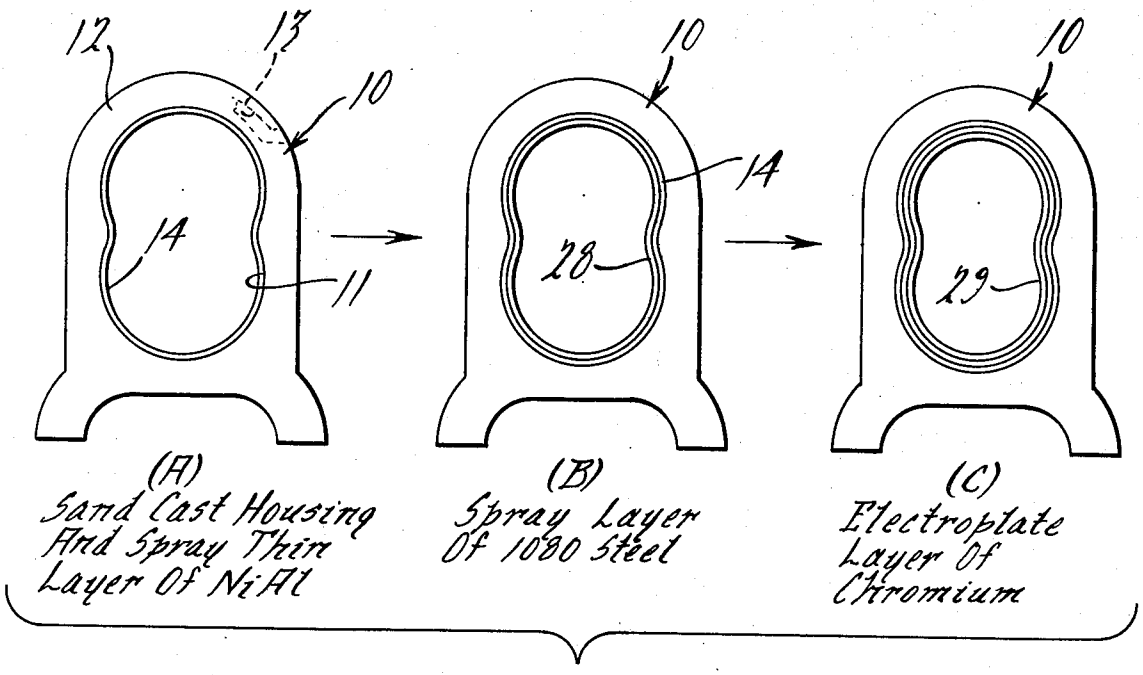

12
13
10
14
11
10
14
28
10
29
(A)
Sand Cast Housing
And Spray Thin
Layer Of Ni Al
(B)
Spray Layer
Of 1080 Steel
(C)
Electroplate
Layer Of
Chromium

Fig. 1.

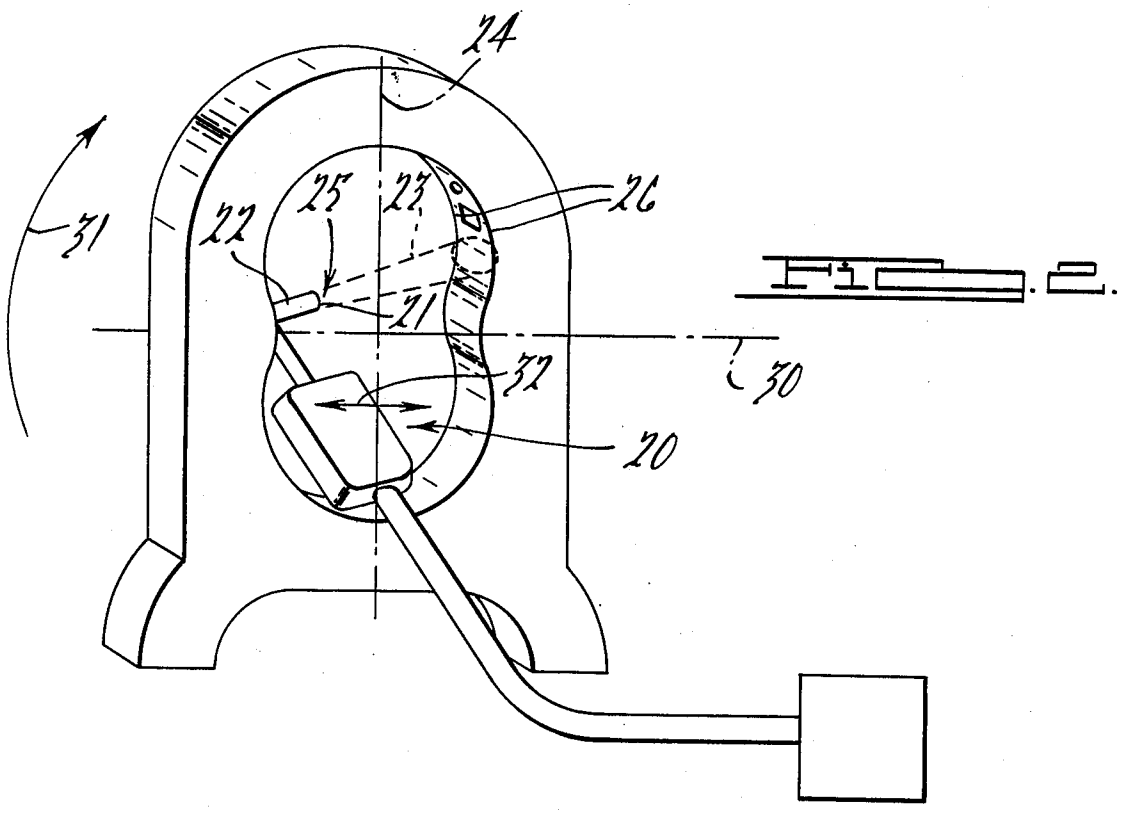

24
31
22
25
23
26
21
30
32
20

Fig. 2.

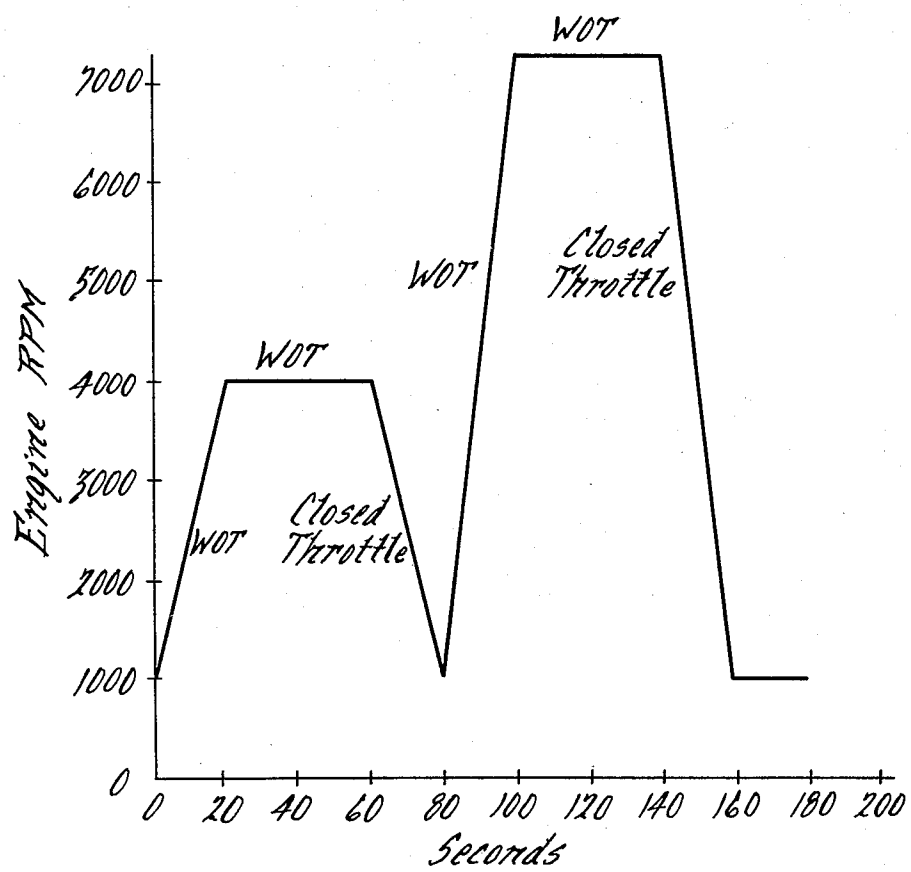

WOT
WOT
WOT
Closed Throttle
WOT
Closed Throttle
Engine RPM
7000
6000
5000
4000
3000
2000
1000
0
0 20 40 60 80 100 120 140 160 180 200
Seconds

Fig. 3.

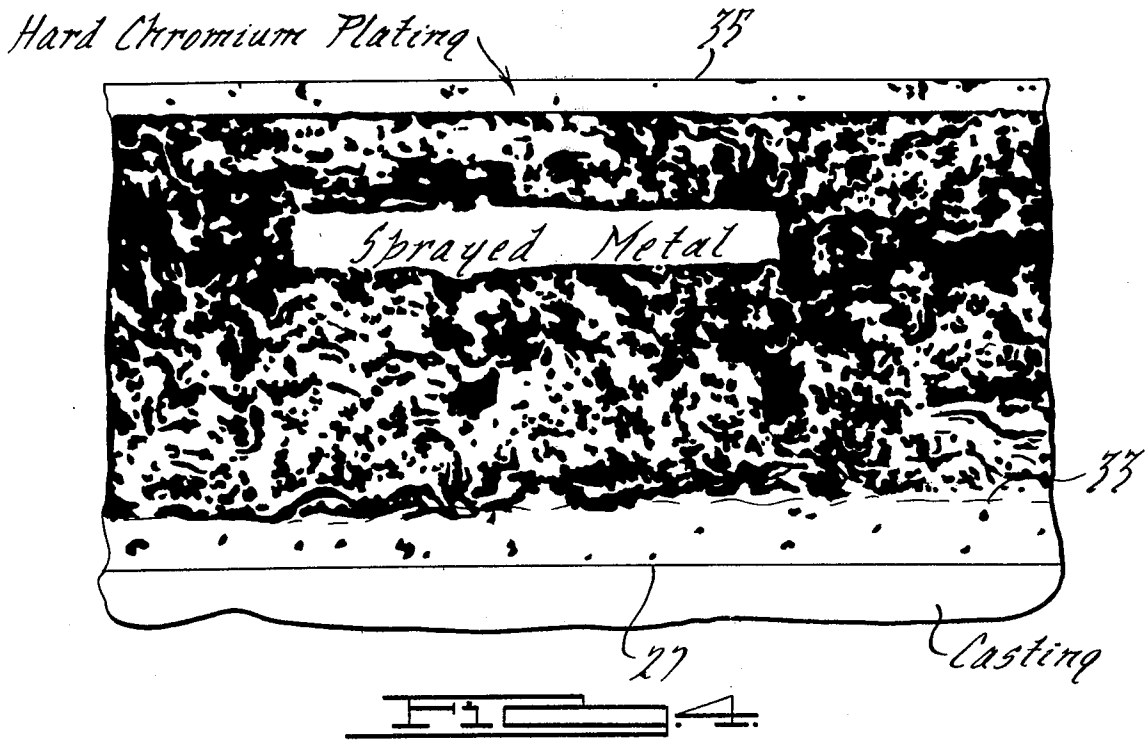

Hard Chromium Plating
35
Sprayed Metal
33
27
Casting

Fig. 4.

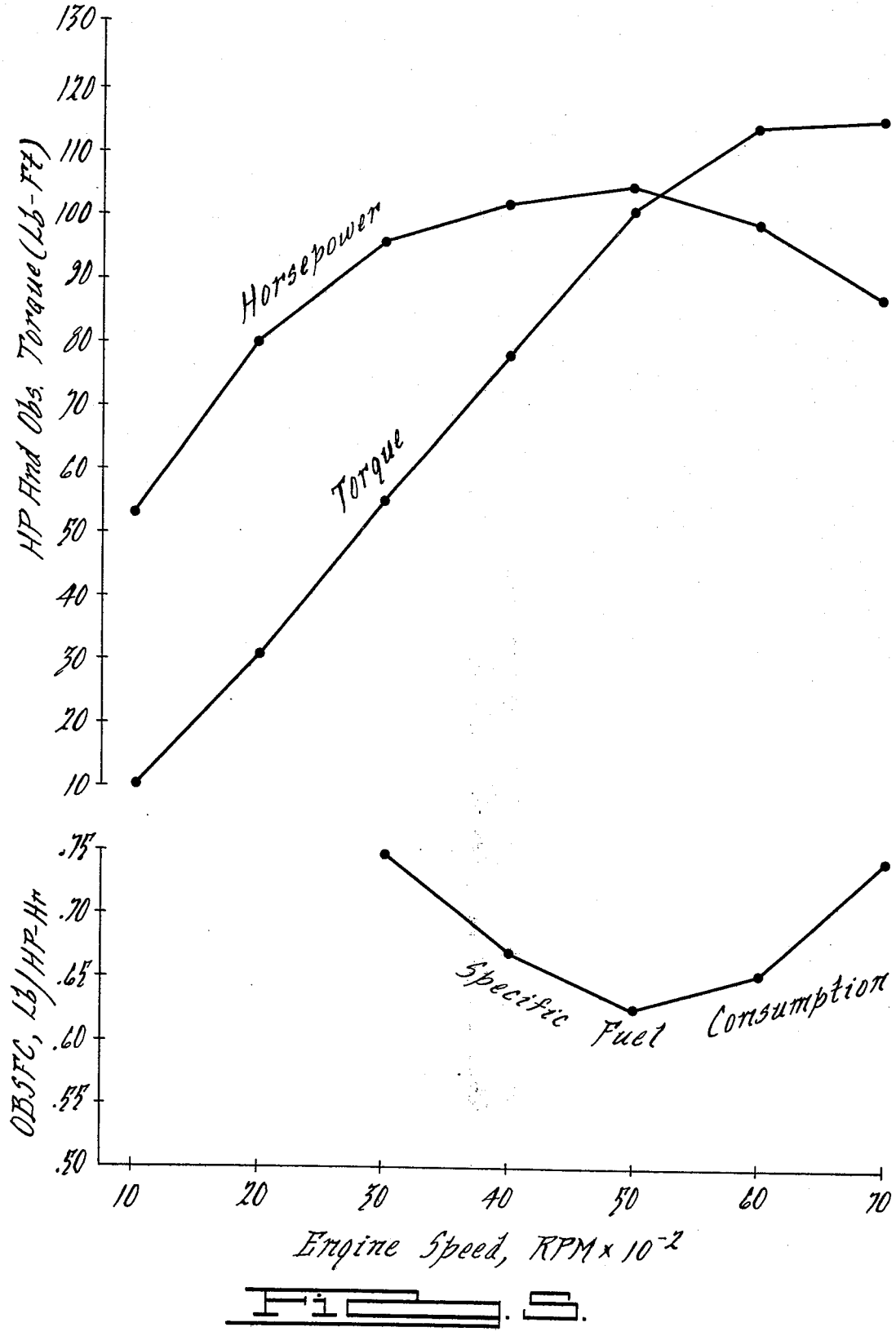

130
120
110
100
90
80
70
60
50
40
30
20
10
HP And Obs. Torque (Lb-Ft)
Horsepower
Torque
.75
.70
.65
.60
.55
.50
OBSFC, LB/HP-Hr
Specific Fuel Consumption
10
20
30
40
50
60
70
Engine Speed, RPM x 10⁻²

Fig. 5.

METHOD OF PROVIDING AN INTERMEDIATE STEEL LAYER FOR CHROME PLATING ON ROTOR HOUSINGS

BACKGROUND OF THE INVENTION

One of the principal demands placed upon the rotor housing of a rotary internal combustion engine is that it must maintain dimensional stability over a long period of engine operation so that the rotor apex seals, rubbing against such housing, will maintain a highly efficient gas seal for promoting efficiency of operation and fuel economy. In order to meet such requirement, the rotor housing internal surface must be highly wear-resistant as well as be capable of retaining dimensional accuracy over a substantial life of the engine.

This has been a difficult requirement to meet, partly because the internal surface of the housing is of a complex shape, particularly an epitrochoid. The reverse curvature of such shape promotes delamination of overlaid coatings under high temperature operating conditions.

One of the more successful combinations of metallurgical materials that has contributed long wear-resistance to a rotary engine is the use of transfer coating defined from low carbon steel, a rotor housing die-cast around such liner, and the electroplating of chromium on the exposed surface of the joined liner. Nonetheless, several drawbacks have become apparent with such a process. One of the most important is the high cost resulting from the mandatory requirement that the liner be placed in a die-casting device rather than use conventional sand-cast mechanisms. In addition, the many steps required of such combination contributes to high cost and increased labor.

Although there have been casual suggestions in the prior art that a plain carbon steel particle mixture may be self-fused directly upon an aluminum housing cast by conventional methods and then subsequently plated with such materials as chromium, these suggestions have been discounted continuously by those who operate in the prior art. Up until the occurrence of the present invention, an inadequate bond has consistently taken place between the interlaying of al-steel-chromium. Bond strengths less than 4,000 psi have been consistently experienced with the flame spraying of powdered steel directly onto cast aluminum followed by chrome plating. This is not a satisfactory bond strength for use in a rotary internal combustion engine.

In addition to the necessity of increasing the bond strength by a more economical method, the necessity for reducing the internal stress of the applied coating is important so that deterioration of the coating will not occur subsequently. Cooling of the coating to ambient temperature conditions has caused considerable stress because little attention was paid to the contraction and expansion characteristics of the elements making up the coating.

SUMMARY OF THE INVENTION

The primary object of this invention is to provide a method of fabricating a rotor housing for a rotary internal combustion engine, the resulting housing being characterized by high wear-resistance and durability while using the combination of a chromium outer layer supported by a conventionally cast aluminum substrate.

Another object of this invention is to provide a method for fabricating a wear-resistant coating of chromium applied to an aluminum substrate, the method being characterized by economy, the lack of necessity for die-casting, reduction in total number of steps and elimination of the need for a transplant.

Yet still another object is to provide an improved method for making a more stress-free aluminum-chromium composite, the composite having a highly adherent intermediate effective to provide a gradual transition in thermal expansion characteristics between the aluminum and chromium elements of the composite.

SUMMARY OF THE DRAWINGS

FIG. **1** is a flow diagram of the essential steps of the present invention;

FIG. **2** is a schematic perspective view of an apparatus useful in the spray coating of an epitrochoid rotor housing in accordance with this invention;

FIG. **3** is a graphical illustration of a hot-cold engine cycle with which the rotor housing, prepared by the method of this invention, is subjected;

FIG. **4** is a schematic illustration of the microstructure of the coated rotor housing casting of this invention; and

FIG. **5** is a graphical illustration of some operating data for an engine embodying the present invention.

DETAILED SPECIFICATION

Direct chromium plating on aluminum rotor housings presents a problem of poor adhesion and inadequate support against the apex seal loads experienced in a rotary engine. One of the current state of the art solutions to this problem employs a transplant technique in which a mandrel is spray coated with steel and the rotor housing is die-cast around the steel coating; a final coating of chromium is plated over the steel coating. Such a method achieves satisfactory bond strength between the steel liner and substrate because steel has a nominal amount of shrinkage when deposited by a flame-spray method; resulting bond strengths of about 12,000 psi have been considered quite adequate for engine applications. However, such technique has involved considerable cost and has unfortunately contributed to the already highly sophisticated technology required for rotary engine manufacture. Means must be found to simplify the techniques used.

In order to provide a composite coating for a rotary engine which is characterized by economy, high bond strength, low internal shear stresses, and economy of casting, the preferred following sequence has been developed (see FIG. **1**):

A. Prepare an aluminum casting to define a rotor housing **10** having an annular configuration with an internal surface **11** shaped as an epitrochoid. The housing is preferably prepared by conventional sand casting technology and should have the side faces **12** of the casting milled so that there is an excess of approximately 0.100–0.120 inch of stock per side which can be milled off at some later time. The epitrochoid surface **11** is machined to have a dimension as the result of this first step which is 0.049–0.050 inch oversize relative to the predetermined final configuration in (C). The machining of the epitrochoid surface **11** should be carried out to provide a surface finish of 64–256 rms.

The casting should be provided with at least one passage or opening **13** formed therein and which opens onto the epitrochoid surface. The margin or mouth of the opening **13** in such surface should be machined to define an accurate dimension for such uses as a spark plug hole, or an intake or exhaust port. The surface **11** should be rough as cast or roughened preferably by light grit blasting using a silicon carbide grit having a size of about 14–24. In lieu of silicon carbide, crushed iron at 40 lbs. per square inch air pressure may be utilized.

While the casting is maintained in the heated condition in the temperature range of 200°–250°F, a thin coating **14** of adherent particles capable of alloying strongly with the aluminum substrate is applied to the epitrochoid surface **11.** The initial coating particles may be selected from the group consisting of nickel aluminides (Ni Al and Ni_3Al), nickel-bronze composites, nickel-chromium composites, molybdenum, and particles with spherical grains, such as nickel-boron carbide (Ni-BC). A preferred composition is about 80% nickel and 20% aluminum (Ni-Al). Such initial coating should be carried out by conventional flame spray techniques whereby the particles are heated by the flame temperature in the gun so that the outer casing of each particle is substantially molten and will form a dense adherent self-fused coating **14** as a result of being impelled against the epitrochoid surface **11.** The coating should be built up to a relatively thin thickness, less than 0.01 inch, and preferably between 0.001–0.008 inch. Both in the initial spray coating of step (A) as well as in the subsequent spray coating of step (B), an apparatus may be utilized, such as shown in FIG. **2.** A flame gun **20** is located with the exit **21** of the nozzle **22** positioned at an off-center location capable of directing the stream **23** to pass through the major axis **24** of the epitrochoid configuration. The nozzle exit should be positioned off-set a distance **25** from the minor axis **30** so that the total stream length will be about **5** inches. The rotor housing may be mounted on a turn mounting, such as a convenient lathe fixture, which is effective to rotate the housing about its own geometrical center according to arrow **31** whereby the full extent of the epitrochoid surface is brought across the path of the stream **23** of sprayed particles. To insure that the full width of the epitrochoid surface is coated, the gun is oscillated from side to side according to arrow **32** at a rate of approximately one inch per minute which covers approximately ½-inch overspray beyond the epitrochoid edges **26.** The rotation of the rotor housing can be carried out at a typical speed of approximately 1 revolution per second. The distance between the exit portion of the nozzle and the area receiving impact of heated particles is here about 4.5 inches at the minimum and 5.5 inches at the maximum. Preferably, the distance traveled by the particle stream should be constant, but this would require additional expense in mounting the epitrochoid surface or gun in a position so that the spacing therebetween can be adjusted in proportion to the complex curvature being brought through the stream.

B. While the housing **10** is still heated from step (A), a second spray coating **28** is applied thereover consisting essentially of plain carbon steel particles. The particles are heated by an oxy-acetylene gun (as shown in FIG. **2**) to impell the particles to impact coating **14** and form a highly adherent second coating **28.** It is important that the plain carbon steel have a carbon content in the range of 0.8–1.2% carbon by weight; a typical chemical analysis for a preferred plain carbon composition would be: 0.80% carbon, 0.04% phosphorous, 0.04% sulfur, 0.7% manganese, 0.1% silicon and the remainder iron. The coating should be built up to a thickness in the range of 0.06–0.09 inch. After the coated casting is cooled to a temperature equivalent to the bath temperature required in the following step, or to ambient temperature conditions, the casting may be preferably given a machining operation whereby the sides are reduced to leave a 0.06–0.08 inch stock on each side; the machining should be carried out so as to machine into the coating rather than away from the coating to prevent imposition of tensile stresses in the coating. The dual-coated epitrochoid surface should be machined to an oversized dimension of about 0.006–0.007 inch and should have a surface finish of approximately 20–30 rms. The edges of the casting should be rounded off with approximately 0.020–0.030 inch radius.

C. The prepared and dual-coated casting is then immersed in a chromium plating solution having a chromic acid-sulfate composition, the chromic acid ratio being about 1:100. Plating current may be about 3–4 amperes/in^2. Bath temperature is maintained at about 132°–135°F. The casting should be constituted as a cathode and a suitable conforming anode of a lead grid should be arranged in the solution so as to set up a potential for electrolyzing the chromium. A plating distance of about three-eighths of an inch may be employed (anode-to-cathode space throughout the epitrochoid). Wax may be used to cover up areas of the surface not to be plated. Also, extra cathodes (or robber elements) may be used to reduce excess build-up of plating at edges.

A hard chromium layer or coating **29** is deposited. The plating step should be carried out for a sufficient time (about 14 hours) and at a sufficient current density to obtain a hard chromium thickness in the range of 0.012–0.015 inch.

Upon completion of the chromium plating, the casting is removed and cooled to room temperature whereby optional finish grinding and lapping may be applied to the chromium layer to produce a finish of approximately 6–8 rms.

The completed tri-coated housing should have a hard chromium layer of between 0.006–0.008 inch thick, an intermediate sprayed steel layer of between 0.041–0.058 inch, a thin alloying underlayer of approximately 0.001–0.01 inch thick and an aluminum substrate produced by sand casting. The composite tri-coating will range in total thickness between 0.048 inch to 0.076 inch. The microstructure of the composite will appear as that shown in FIG. **4**; the nickel-aluminide layer will have a flat side **27** adhering to the dimensionally stable casting epitrochoid surface **11.** The opposite side **33** will have a more irregular surface due to the porosity inherent in a powder-sprayed layer. The outer polished and lapped surface **35** of the chromium coating will have minute cracks due to residual stresses and heat checking when at operating temperature (about 400°F).

Most importantly, internal stress of the casting-coating composite is reduced. The coefficient of thermal expansion of aluminum is about 13×10^{-6}/°F, and for 1080 steel it is about 6.5×10^{-6}/°F. If powdered

1080 steel is sprayed directly onto aluminum, each will undergo a distinctly different dimensional change upon cooling from the high processing temperature. Accordingly, considerable internal stress can be built up in the coating causing premature failure under prolonged engine operation. However, with this invention, the nickel-aluminide (or other first coating) is interposed to bridge the difference in thermal expansion characteristics. The particular nickel-aluminide may have a coefficient of thermal expansion in the range of about 7.4–8.5 × 10^{-6}/°F. In addition, nickel-aluminide (or other first coating) increases the bond strength to aluminum to about 5,000 psi.

Looking at FIG. 5, engine performance over normal engine speeds shows horsepower and torque has been slightly increased as a result of the more efficient coating system. Fuel consumption remains about equal to typical values for a commercial rotary engine.

TEST RESULTS

The coated housing, according to the present method, is subjected to a variety of tests. The most critical test to determine whether the composite coatings have sufficient adhesion to withstand operating temperatures and conditions of a rotary engine is the hot-cold cycle. As shown graphically in FIG. 3, this essentially comprises a cycle which consists generally of two parts. In the first part, the engine is run with cooling water held at a temperature of approximately 220°F. The engine is initially run at 1,000 r.p.m. for 3 minutes at no load; the engine is then moved from 1,000 r.p.m. quickly to 4,000 r.p.m. for approximately 40 seconds and then the throttle is closed (closed throttle) to allow the engine to return to 1,000 r.p.m. (20 seconds). The engine is then moved up to 7,000 r.p.m. (20 seconds), held at such level (wide open throttle) for 40 seconds, and then the throttle is closed to return to 1,000 r.p.m. (20 seconds). At this point, the cooling water is immediately changed and reduced to 90°F. As soon as the engine is run at 1,000 r.p.m. for 3 minutes with the cooler water, the engine is then moved from a 1,000 r.p.m. to 4,000 r.p.m. under wide open throttle (20 seconds) and held at the latter r.p.m. level for 40 seconds and then dropped to 1,000 r.p.m. (20 seconds); then up to 7,000 s.p.m. This same cycle is repeated continuously night and day until the engine has accumulated running hours in the neighborhood of over 100.

With the method of this invention, the rotor housing has experienced in excess of 180 hours and run as much as 200 hours before engine breakdown resulting from other problems not connected with the adherency or efficiency of the coating. Upon engine tear-down, the rotor housing chromium surface did show a macro-crack pattern over the entire layer. A very faint (almost unnoticeable) chatter marks were on the composite surface. The apex seal crowns (graphite) used with these tests showed little wear, although some of the crown radius was lost. A few pits occurred on the leading edges of some of the seals. The measured wear rate averaged less than the 75 micro-inches/hour for the best of prior art constructions. There was a definite increase in efficiency as exhibited by the data in FIG. 5.

MICROSTRUCTURE

To measure bond strength of the coatings, it has been typical to spray or plate deposits of the coatings on at least one of two flat test specimens; the coated portion is joined to the other test specimen typically by an epoxy adhesive. Upon hardening of the adhesive, the specimens are pulled apart along the plane of the specimens which will dominantly be shear.

To more fully reflect the bond strength under tension which will more readily be experienced in rotary engine applications, two cylindrical bars are flame sprayed (and plated) on their ends with the appropriate coatings. The coated ends are aligned, butted, and cemented together by a band of adhesive encircling the butted ends and overlapping each coated portion. The bars are then pulled apart along their aligned axes in a tensile testing machine. The tensile load to pull the coating apart from the cylindrical bars, divided by the circular area of the bond, is the tensile bond strength. Using this invention, tensile bond strengths can be increased to about 5,000 psi.

We claim:

1. A method of fabricating a rotor housing for a rotary internal combustion engine, comprising:
   a. preparing an aluminum casting defining said rotor housing having an annular configuration with an internal surface shaped as a trochoid, said casting having dimensionally machined sides and a rough as-cast trochoid surface, said casting having at least one passage opening into said surface which is temporarily closed by an inert plug during subsequent processing,
   b. with said casting maintained at a temperature of at least 200°F, applying a thin self-fused coating of heated nickel-aluminide particles across said entire trochoid surface to form a layer thereon with a thickness no greater than 0.01 inch,
   c. immediately applying a uniform coating of carbon steel particles having at least the outer surfaces thereof heated to a temperature of at least 2,000°F for self-fusing when impelled against said first coated casting surface,
   d. cooling said second coated casting to a temperature generally equal to or below the bath temperature of a selected chromium plating electrolyte, immersing said coated casting in said electrolyte and applying sufficient potential between an anode and said casting to deposit a third thin coating constituted of chromium on said casting surface in the thickness range of about 0.007 inch, and
   e. cooling said tri-coated casting to ambient temperature conditions in a manner to insure a reduced internal stress condition of said coating, said triple coating having a combined thickness in the range of 0.048 to 0.076 inches.

2. The method as in claim 1, in which the plain carbon steel particles have a carbon range of between 0.8–1.2% by weight.

3. The method as in claim 1, in which the nickel-aluminide coating has an average thickness in the range of 0.001–0.008 inches.

4. The method as in claim 1, in which the plain carbon steel particle coating is deposited in a uniform thickness of at least 0.06 inches.

5. The method as in claim 1, in which the first coating layer is comprised of NiAl.

6. The method as in claim 1, in which the first coating layer is comprised of a material selected from the group consisting of the following particle chemistries: NiAl, Ni-bronze, Ni-Chromium, Ni-BC, and molybdenum.

7. The method as in claim 1, in which the trochoid surface of said rotor housing casting is machined to a finish of about 64–256 r.m.s. prior to deposition of any coatings thereon, said machining being followed by a very light grit blasting.

8. The method as in claim 1, in which the carbon steel coating of step (c) is deposited in a thickness at least 5 times the maximum thickness of said Ni-Al coating.

9. The method as in claim 1, in which the chromium coating is machined to a surface finish of about 20–30 r.m.s.

10. The method as in claim 1, in which the Ni-Al coating of step (b) is comprised of about 80% nickel and about 20% aluminum.

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