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(54) BORONIZED DRILL BIT CUTTERS AND METHODS

(71) We, HUGHES TOOL COMPANY of 5425 Polk Avenue, Houston, Texas 77023, United States of America, a company incorporated under the laws of the State of Delaware, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed to be particularly described in and by the following statement:—

This invention relates in general to earth boring drill bits, particularly to metallurgical treatments that increase the wear resistance and hence the life of cutters and teeth exposed to abrasive wear.

The common prior art method for retarding the abrasive wear of earth disintegrating teeth and cutters used in earth boring drill bits is the application of hardfacing to selected surfaces. A typical hardfacing used on teeth and cutters is a composite material consisting essentially of an alloy steel matrix in which are dispersed particles of sintered tungsten carbide. This composite material is applied by a welding process by which a steel tube filled with tungsten carbide particles and ferroalloys is heated to a temperature sufficient to melt the steel tube and to fuse the composite to the selected surfaces. As a result, a strong metallurgical bond is created. Unfortunately, melting the metal of the tooth causes a weakening of the tooth, particularly under impact loads. Thus, there exists a long standing problem of premature tooth breakage when heavy loads are applied to hard-faced teeth during earth drilling. The subsequently described invention is directed primarily to a solution to this problem.

Previously, it was thought that boronizing teeth and cutters would improve their abrasive wear resistance, but the extremely brittle nature of the resulting boronized surfaces led to the formation of detrimental cracks. As a consequence, the problem became how one could obtain the advantages of the extremely hard and wear

resistant boronized surface in a manner compatible with the other metallurgical requirements of the teeth and cutters.

According to the invention there is provided a method of manufacturing steel rotatable cutters for earth boring drill bits comprising the steps of: forming a cutter with exterior earth disintegrating teeth; carburizing the exterior of the cutter, or selected areas thereof, to produce a carburized case of selected depth; boronizing said carburized case to produce a boronized case of selected depth; and heat treating exterior of the cutter, or each said selected area thereof, has an extremely hard and wear resistant boronized case over a deformation resistant carburized case.

Preferably, said heat treatment comprising hardening in a manner to produce martensitic structure in the carburized case, and tempering to produce thereafter tempered martensite, whereby a surface of extreme hardness results with a strong and tough supporting base. This base minimizes fracturing of the brittle boronized case since it is resistance to deformation and provides a satisfactory support for the boronized case. The resulting surface is sufficiently abrasion resistant to replace the hardfacing of the prior art. Tooth failure due to weakening as a result of the prior art hardfacing operation is therefore minimized.

In order that the specification may be fully understood reference is made to the accompanying drawings in which:

Fig. 1 is a perspective view of an earth boring drill bit having cutters and teeth which receive the metallurgical treatment described herein.

Fig. 2 is a side elevation of another type of cutter used in an earth boring drill bit, such cutter having a gage surface, heel row, intermediate row and inner row of teeth to dislodge cuttings from a borehole bottom during drilling.

Fig. 3 is a fragmentary side elevation, partially in section, showing a rotatable cutter mounted on suitable bearing means

extending in cantilvered fashion from a drill bit leg or head section.

Fig. 4 is a fragmentary side elevation view, partially in section, of an alternate form of cutter and teeth used in drilling, such cutter teeth having the metallurgical treatment described herein.

The numeral 11 in the drawing designates a typical earth boring drill bit having a threaded shank 13 for attachment to a drill string member, nozzles 15 for directing a flow of fluid toward a borehole bottom, and in this instance three depending legs or head sections 17 that each support a toothed, rotatable cutter 19.

In Fig. 2 is shown an alternate form of cutter which has the typical conical basic configuration, including a conical gage surface 21 extending from the cone back face 23 to the heel row teeth 25. The gage surface is formed with alternate areas of steel ribs 27 and bands 29 of a composite hardfacing material consisting essentially of an alloy steel matrix and particles of sintered or cemented tungsten carbide. This particular cutter has an intermediate row 31 of teeth and an extreme inner row or spear point 33.

A cutter such as that shown in Fig. 2 is generally mounted on a leg or head section 17 (see Fig. 3) with a cantilevered shaft or bearing pin 35 that forms a bearing on the interior of the cutter. The particular bearing illustrated is primarily of the anti-friction type, having a row of roller bearings 37, a row of ball bearings 39, and two friction bearings that utilize a bushing 41 and a thrust button 43.

In Fig. 4 is shown an alternate form of rotatable cutter and bearing configuration in which the cone 19 has its heel row 25, intermediate row 31, and inner row 33 formed with wear resistant inserts or compacts, preferably constructed in the prior art of cemented tungsten carbide with a cobalt binder, and inserted with interference fit in matching holes drilled into the cone exterior. The gage surface 21 has a row of gage packs 45 substituted for the hardfacing 29 used on the Fig. 2 type cone configuration. The head section 17 and its cantilevered bearing pin 35 have a friction bearing 47 in place of the rollers 37 in the Fig. 3 embodiment, and in addition, have a row of ball bearings 39, and friction bearings utilizing the bushing 41 and thrust button 43. In this instance a seal such as an o-ring 49 is placed in a suitable groove between the bearing pin 35 and cutter 19 to retain a lubricant within the bearing region.

This invention is best practised through utilization of four method steps: carburizing, boronizing, hardening and tempering, each of which will be described separately by way of example. The initial

step in the method requires carburizing the rotatable cutter or selected areas thereof for example in the cutter of Figure 2, the teeth and the hard faced gage surface of the cutter may be carburized. One of the prior art carburizing methods may be used. Gas carburizing is a well known art and is the preferred method. It is described on pp. 93—114 of Volume 2 of the 8th Edition of the Metals Handbook, "Heat Treating, Cleaning and Finishing" (1964, American Society for Metals). An example of the gas carburizing of a rotatable cutter made of A.I.S.I. 4815 steel is as follows:

Carburizing temperature: 927°C
Carburizing time: Nineteen hours at 927°C
Carburizing atmosphere: Generated endothermic gas enriched with methane to have a carbon potential of 1.35% carbon. A typical analysis of the carburizing gas (atmosphere) is as follows:

40% N₂
20% CO (CO₂ about 0.05%)
38% H₂
2% CH₄

This produces a carburized case depth of about 2.18 mm with carbon content at the surface about 1.00%.

Pack carburizing is another well known art that may be used. It is described on pp. 114—118 of Volume 2 of the Metals Handbook. An example of pack carburizing of a cutter made of A.I.S.I. 4815 steel is as follows:

Carburizing compound (in which cutter is packed): Charcoal, 90% (3.32 to 1.17 mm in size), energized with about 4% BaCO₃ and about 1.5% CaCO₃.

Carburizing temperature: 927°C
Carburizing time: Nineteen Hours at 927°C

This produces a carburized case depth of about 2.18 mm with carbon content at the surface about 1.00%.

Liquid carburizing is another well known art to the metals industry. It is described on pp. 133—145 of Volume 2 of the Metals Handbook. While not actually used for this invention, it is anticipated that nineteen hours at 927°C in a salt bath containing about 6—16% sodium cyanide and 30—55% barium chloride would produce a satisfactory carburized case to a depth of about 2.18 mm.

The second step of the method of this invention is boronizing of the previously carburized exterior surface and teeth. Pack boronizing is the preferred technique and is a relatively new art.

An example of boronizing the exterior surface of a carburized A.I.S.I. 4815 steel cutter is as follows:

Compound: Boronizing powder was packed around the carburized bearing exterior surface. This powder was 90% finer than 0.104 mm, had 40–80% B_4C_3 , 2–40% graphite, 1–4% $KHCO_3$, with remainder up to 20% impurities.

Boronizing temperature: 900°C in a carburizing atmosphere.

Boronizing time: 8 hours at temperature in a furnace with a carbon potential of 1.00%.

This produced a boronized case depth of about 0.12 mm. Longer boronizing times and/or higher boronizing temperatures can be used for deeper boronized case depth, but a 0.025 to 0.25 mm deep boronized case has less tendency to crack or spall than a deeper case.

Gas boronizing is an alternate technique in the prior art. It is described in U.S. Patent No. 2,494,267, "Surface Hardening of Ferrous Metals", Schlesinger and Schaffer, Jan. 10, 1950. The method described utilizes gaseous diborane (B_2H_6) at about 700°C (1292°F).

Liquid boronizing is another prior art boronizing method. It is described in two papers: "Boronizing of Steel" by D. C. Durrill and Dr. Donald D. Allen, Magnetic Propulsion Systems, Inc. and "Boriding Steels for Wear Resistance" by Howard C. Fielder and Richard J. Sieraski, General Electric Co. (*Metal Progress*, Feb. 1971, pp. 101–107).

Neither gives the liquid salt bath composition, but the latter paper states that it contains fluorides of lithium, sodium, potassium, and boron. Temperatures and times reported vary from 788°C–900°C and from 15 minutes to 36 hours.

The third and fourth steps in the method of this invention are hardening and tempering of the carburized boronized and cleaned steel surfaces.

The hardening and tempering of carburized steel is a well known art. The hardening, usually quenching in agitated oil, from a temperature of at least 755°C, can be performed using one of the following procedures for carburized A.I.S.I. 4815 steel to produce a substantially martensitic case:

(a) Double quench from a carburizing or reducing atmosphere and temperatures of respectively 843°C and 780°C is preferred.

(b) Single quench from a carburizing or reducing atmosphere and a temperature of 816°C.

De-carburization or oxidation of the boronized case may be prevented by using a carburizing or reducing atmosphere or by a coating such as copper plating. A suitable atmosphere is similar to the previously explained methane enriched endothermic gas except slightly higher in CO_2 (about 0.4

to 0.8%) because of the lower temperatures.

The tempering temperature is usually low, 143°C–266°C, preferably about 166°C for one hour, to toughen the carburized case without appreciably lowering its strength (hardness) to produce tempered martensite.

A satisfactory method for boronizing drill bit cutters and teeth produces a carburized foundation on the steel cutter of at least 0.762 mm. In addition a boronized case of at least 0.025 mm is produced (average about 0.127 mm) with a surface hardness in a range of about 900 to 2100 KHN. The hardening and tempering procedure develops a hardness in the carburized foundation in the range of about 50 to 64 Rockwell "C" (550 to 800 KHN). (KHN stands for Knoop Hardness Number which is a scale commonly used in the art to measure extremely hard materials.)

Three rotatable cutters treated in accordance with the foregoing first examples were assembled with head sections to form an earth boring drill bit, which was secured during operation to the lower end of a drill string member by threads 13 (see Fig. 1). The drill string was then lowered and rotated to urge the cutter teeth in the earth's formations. The bits of the present invention in actual drilling exhibited resistance to abrasive wear comparable to that obtained with the prior art hardfaced teeth. In addition, there was a significant reduction of tooth breakage in most instances since the method of this invention did not detrimentally affect the strength of the teeth. Thus, even though the extremely hard boronized case was relatively shallow, the carburized, hardened and tempered supporting base was sufficiently resistant to deformation to avoid fracture of the boronized case. Simultaneously, the boronized case had sufficient abrasion resistance to retard wear over the normal life span of the drill bit.

While the invention has been described in only a few of its forms it should be apparent to those skilled in the art that it is not so limited but is susceptible to various changes and modifications within the scope of the appendant claims. The entire exterior surface of a cutter such as that shown in Fig. 3 may receive the treatment of the invention. On the other hand individual teeth such as the inserts shown in Fig. 4 may be treated according to the invention and substituted for the prior art inserts. Or the cutter surfaces surrounding prior art tungsten carbide inserts may be treated according to the invention to prevent cone surface erosion between the inserts. In summary the invention will find many applications in which wear resistance, strength and durability are required.

WHAT WE CLAIM IS:—

1. A method of manufacturing steel rotatable cutters for earth boring drill bits comprising the steps of: forming a cutter with exterior earth disintegrating teeth; carburizing the exterior of the cutter, or selected areas thereof, to produce a carburized case of selected depth; boronising said carburized case to produce a boronized case of selected depth; and heat treating said carburized case for selected hardness; whereby said exterior of the cutter, or each said selected area thereof, has an extremely hard and wear resistant boronized case over a deformation resistant carburized case.

2. The method according to claim 1 wherein said selected areas of the cutter include said earth disintegrating teeth.

3. The method according to claim 1 or claim 2 wherein said selected areas of the cutter include cutter surfaces immediately surrounding said earth disintegrating teeth.

4. The method according to claim 1 and comprising the steps of: forming a generally conical cutter with exterior earth disintegrating teeth; hardfacing a gage surface on the cutter to define means for cutting and abrading on the wall of a bore-hole; carburizing at least said teeth and said gage surface to produce a carburized case of selected depth; boronizing said carburized case; heat treating said carburized case for selected hardness.

5. The method according to any of claims 1 to 4 wherein said heat treating comprises hardening and then tempering.

6. The method according to claim 5 wherein the hardening of said carburized case is performed by quenching from a temperature to produce a martensitic grain structure; and the tempering of said

carburized case is performed to produce a tempered martensitic grain structure.

7. The method according to any of claims 1 to 6 wherein said carburizing is performed to produce a carburized case of at least 0.76 mm; and the boronizing of said carburized case is performed to produce a boronized case to a depth of at least 0.025 mm.

8. The method according to claim 7 and comprising the steps of: quenching said carburized case from a temperature of at least 755°C to produce a martensitic grain structure; and tempering said carburized case from a temperature within a range of 143°C to 266°C to produce a tempered martensitic grain structure.

9. A steel rotatable cutter for an earth boring drill bit manufactured according to the method of any of claims 1 to 8.

10. A cutter according to claim 9 wherein the hardness of the surface of the carburized case is within a range of 550 to 800 KHN.

11. A cutter according to claim 9 or claim 10 wherein the surface hardness of the boronized case is within a range of 900 to 2100 KHN.

12. The method of manufacturing steel rotatable cutters for earth boring bits, the method being as hereinbefore described with reference to the accompanying drawings.

13. A steel rotatable cutter for an earth boring drill bit according to any of claims 9 to 11 and substantially as hereinbefore described with reference to the accompanying drawings.

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