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Production of Tantalum Carbide Tool Bit Using Powder Metallurgy Process

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Abstract*: The paper provides an advanced method of manufacturing tantalum carbide tool bit using powder metallurgy process. The said method is used to manufacture the tool bit. This tool bit is then tested for the machining of various materials. The results obtained are documented and compared with the typical cutting materials used in industries. The method implemented for powder production is chemical reduction. The green compact is prepared using unidirectional pressing. The design of components used for pressing i.e. die and punch are stated. The sintering process is done using inert atmosphere in an electric furnace. In depth calculations are listed for the various mechanical operations involved. Changes in physical and chemical properties at various stages are tabulated. The tool bit manufactured is tested for machining of various materials and the results are recorded and comparative study is provided.
***Keywords*: tantalum carbide, tool bit, powder metallurgy, chemical reduction, sintering**

I. INTRODUCTION

In the recent years, the scenario in manufacturing industries has greatly changed. There is now a demand for cutting tools with better machining capabilities like higher machining speed and better surface finish. These qualities are expected at low cost and minimum maintenance of tools. Cemented carbides do provide better machining capabilities but their application has been limited over the past owing to difficulties in manufacturing methods are difficult and greatly increase the cost. The advent of powder metallurgy has paved a way to provide a solution to this drawback.

Powder metallurgy is a technique specially developed for production of components which otherwise are difficult to manufacture using conventional methods like casting, machining or forging. Components like porous bearing are nearly impossible to manufacture using other production methods. It is also suitable for manufacturing components which are very hard and difficult to machine. [1]

Tantalum carbide is one of the materials which may be used for machining of very hard materials. The production of tantalum carbide by conventional processes such as casting, machining or forging is very difficult. It can be suitably manufactured using powder metallurgy. The process is explained in this paper in detail.

II. POWDER METALLURGY PROCESS

The first step in powder metallurgy is production of the powder from which the component is to be made. Various processes are available for this, including chemical reduction, crushing of ore and atomization. The powder obtained is then compacted using press machines to produce a near net shape component called green compact. If the component material is a mixture of more than one material, an intermediate step for homogenization of the mixture is also necessary before compacting. The green compact obtained by die pressing lacks the strength. The strength is introduced using sintering operation. Sintering is a process in which the green compact is heated to a temperature which is just below the melting point of the material. This results in infusion of the material at a molecular level. [2]

The sintered component is of near net shape. Additional secondary processes such as machining are recommended if the dimensional conformity required is very high. This is an overview of the powder metallurgy process. The process developed and used specifically for tantalum carbide tool bit production is explained later.

III.PROPERTIES OF TANTALUM CARBIDE

Tantalum carbide is a chemical compound of tantalum and carbon with the formula TaCx, where x usually varies between 0.4 and 1. The most common phases are TaC and TaC2. A typical composition of tantalum carbide consists of 94% Tantalum and 6% Carbon by weight. It usually appears as amorphous powder which is dark brown or gray in color. It has very high density of 14500 kg/m³ and melting point of 3880 °C, which is slightly less than the melting point of tantalum hafnium carbide which is 3942 °C.

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It also has very high hardness of more than 9 Mohs. Other properties include bending strength of 590 MPa, compressive strength of 2700 MPa and friction coefficient of 0.07.

IV. APPLICATIONS OF TANTALUM CARBIDE

Tantalum carbide is widely used as a Refractory ceramic material. It finds its main application in production of cutting tools and tool bits. It is also used as an additive to tungsten carbide or tungsten cobalt alloys, which again are used for production of cutting tools and tool bits. An alternative to use as a cutting tool or tool bit is that it may be used as a coating on High speed steel tools, thereby eliminating the need for a high cost tantalum carbide tool or tool bits. The coating is usually done by chemical vapor deposition (CVD). Other applications include coating for steel molds in the injection molding of aluminum alloy, production of sharp instruments with extreme mechanical resistance and hardness, next generation thermal heat protection, space air craft components, automotive wear resistant liners, and propulsion exposed components. It is also used in optical coatings, electrical contacts and diffusion barriers. [3]

V. POWDER PREPARATION

Powder production is the first step in the powder metallurgy process. The tantalum carbide powder is prepared using reduction - carbonization method. Oxide or ore of tantalum i.e. Ta_2O_3 along with carbon black is heated to 1700 °C in an electric furnace. Tantalum carbide has a tendency to react rapidly with oxygen, especially at high temperatures. Hence, an inert atmosphere of hydrogen is provided. The direct carbonization of sponge of tantalum and carbon black occurs. The general reaction is

$Ta_2O_5 + 7C = 2TaC + 5CO$

VI. POWDER HOMOGENIZATION

The second step, after powder production is powder homogenization. The powder produced in the first step is put in a ball mill. This results in production of powder which has uniform particle size, which results in better finished product quality. During this process, additional additives are also added along with tantalum and carbon. These additives have two main applications. First, they provide inter molecular lubrication which is helpful during die compacting. The lubricant helps in sliding of molecular layers which results in production of green compact which has higher density. Second, these additives become active during sintering, and aid in infusion of the tantalum carbide particles at a molecular level. This imparts better product characteristics such as higher hardness. [4] [5]

VII. DIE COMPACTION

The third step after powder homogenization is die compacting. The powder of tantalum and carbon is filled in die cavity and cold pressed. Due to the application of high pressure, the powder is compacted resulting in a part which is similar in shape to the die cavity and also resembles the finished product geometry. This part is called green compact. The pressing done is unidirectional. This results in simpler die design and faster production of the part.

VIII. SINTERING

The green compact obtained after die pressing is strong enough to retain its shape, but not strong enough to be used for cutting. This is because the powder components i.e. Tantalum and carbon are present in compact form only, without infusion of the molecules. To achieve the infusion at molecular level, the green compact is heated just below its melting point using spark plasma furnace. This process is called sintering. Since tantalum has a tendency to react actively with oxygen, especially at high temperatures, the green compact is heated in an inert atmosphere of hydrogen. The temperature ranges from 2000 to 2400 °C. It is observed that the infusion at molecular level is higher at 2400 °C and hence recommended and used. However, grain structure at both the temperatures is observed to be similar. [6]

IX. ADVANTAGES

Tantalum carbide tool bits have excellent resistance to wear and abrasion. It also has excellent resistance to corrosion, oxidation and erosion. Cutting speeds of up to 8 times higher than high speed steel tools may be obtained. The surface finish obtained is also better due to its superior flatness capability and conformable on intricate geometries. Tantalum carbide has ultra and pure graphite

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sub straight along with dimensional stability, thermal shock resistance and being non-porous. Other properties include uniformity of grain structure and high electrically conductivity.

X. DISADVANTAGES

In spite of the many advantages of tantalum carbide tools, they have certain inherent disadvantages. For example, they are not as tough as high speed steel tools. This may lead to chipping and breakage of the tool if sudden loading occurs during machining. Tantalum carbide tool bits are costly owing to the high cost of raw material and manufacturing method implemented.

To overcome both these disadvantage, it is a common practice to manufacture only the tool bit using tantalum carbide and then attaching it to a shank of high speed steel tool. By this practice, the tantalum carbide edge does the machining while the sudden loads are absorbed by the more strong high speed steel tool shank. Also, as the tool bit is made of high cost tantalum carbide and the shank is made of low cost high speed steel, the cost of tooling is considerably reduced. Though the bits have long live, they are not easily shaped or sharpened for reuse once the original cutting edge is eroded. [7] [8]

XI. CONCLUSION

The tantalum carbide tool bit is produced using the processed described above. The tantalum carbide tool bit is then attached to a shank of high speed steel. The arrangement is used to machine mild steel and high carbon steel. The tools are fit on lathe machine and operations performed are facing and turning. The tool life at various speeds, feed and depth of cut is documented. It is observed that the tool bit life is eight times better than that of tools made entirely of high speed steel. These characteristics are obtained without re grinding of the tool tips.

XII. FUTURE SCOPE

Tantalum carbide tool bits will have a larger market if the cost is reduced. A large room of cost reduction lays with production method described here i.e. powder metallurgy. Improvement in powder metallurgy method will greatly reduce the cost, making its use more cost effective. Re grinding operations can be developed to suit the tantalum carbide tool bits which will result in higher tool re usability.

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