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Functionally Graded Tungsten Carbide Produced by Carburizing Method

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Cemented tungsten carbide (WC-Co) is an indispensable material used in many manufacturing sectors including metalworking, oil and gas drilling, geothermal energy exploration, mining, construction, high-wear components, and other applications. The wide range of applications of WC-Co is because of its superior combination of high modulus, high hardness, wear resistance, and moderate fracture toughness. However, the wear resistance and fracture toughness of WC-Co composites are inversely related to each other. Wear resistance is often improved at the expense of the fracture toughness, and vice versa. This, in turn, limits the potential use of the material in manufacturing operations.

One method for improving the fracture toughness without sacrificing wear resistance (or vice versa) of WC-Co materials is to use functionally graded WC-Co composites that have varying cobalt content from surfaces to the interior. With the cobalt gradient, the hardness and toughness of the material change correspondingly. The surface of the part with relatively low cobalt content has high wear resistance, while the interior of the part with relatively high cobalt content exhibits high toughness. The functionally graded structure with cobalt gradient thus offers advantages in terms of the combinations of fracture toughness and wear resistance in comparison to the conventional homogeneous WC-Co materials.

Manufacturing functionally graded WC-Co, however, presents a difficult problem. Cemented tungsten carbide is typically sintered via liquid phase sintering process in vacuum. When WC-Co with an initial cobalt gradient is subject to liquid phase sintering, the migration of liquid phase can easily occur and any gradient of cobalt content is easily eliminated. A solution to this problem is to employ pressure assisted sintering techniques such as Hot Isostatic Pressing (HIP) and spark plasma sintering to consolidate the graded WC-Co compact at solid state. However, these alternative processes have limited industrial applications because the high pressure processes are very costly.

In the past several years, Fang, Fan and their students at Department of Metallurgical Engineering, University of Utah have conducted extensive research [1-3] to understand the cobalt migration phenomenon and the dependence of cobalt distribution as functions of cobalt content, grain size, and carbon content. Assuming there are two layers or regions of WC-Co material with different grain size, cobalt content, or carbon content, cobalt will migrate from one area with higher cobalt content to another with lower cobalt content, from areas with coarse grain size to that with finer grain size, and from areas with higher carbon content to that with lower carbon content. These enhanced fundamental understandings on the migration and redistribution of cobalt during liquid phase sintering enables the development of an innovative process that can economically produce functionally graded WC-Co.

The new process is a post-sintering carburizing heat treatment process for manufacturing functionally graded WC-Co [4-8]. In this process, the Co gradient is formed by heat treating conventional liquid-phase-sintered WC-Co in a carburizing atmosphere at temperatures that allow three-phase equilibriums among solid tungsten carbide, solid cobalt, and liquid cobalt. The process exploits the thermodynamic equilibriums among the three different phases and the dependence of the equilibrium on temperature and carbon content.

The mechanism of graded structure formation during the process is summarized as follows:

- Surface carburization occurs;
- Solid Co in surface region partially or totally transforms into liquid Co;
- Liquid Co in surface region increases;
- Balance of liquid Co distribution between surface and core regions is broken;
- Liquid Co migrates from surface region to core region; and finally
- Graded structure forms with low Co at the surface and high Co in the core.

Mechanical property testing of many functionally graded WC-Co samples produced by this process has been conducted to evaluate the benefits of the functionally graded WC-Co over conventional WC-Co with homogeneous structure. The evaluation has clearly indicated a significantly improved wear resistance without decreasing the fracture toughness.

Drilling tools using the functionally graded WC-Co have been field-tested for their performance in oil and gas drilling, mining and construction. It has been confirmed that the superior combination of mechanical properties of the functionally graded WC-Co indeed results in significantly improved tool life. In some applications, tool life has been found to increase by over 100%.

One of the most valuable characteristics of the process lies in that the process is extremely cost-effective, since it is a simple post-sintering heat treatment process. Another valuable characteristic of the process is that it can produce functionally graded WC-Co by treating a wide variety of WC-Co grades with different Co contents and WC grain sizes. Thus, the produced functionally graded WC-Co can meet the needs of a wide variety of manufacturing industries.

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