CHARACTERIZATION OF ZIRCONIA COATED HSS BUTT WELDFLASH CUTTING TOOL

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ABSTRACT;
Various surface techniques have been developed to improve the wear, corrosion resistance of cutting tool materials. One of the most effective methods is to deposit a protective coating on the cutting tool surface. Coating increases life and efficiency of cutting tool. Coating of the tool will enhance the properties of like physical, mechanical, thermal and chemical properties. The operation of removing the flash metal from the base metal is called flash trimming. Many researches have been carried out regarding cutting tool coating where the base metal is at room temperature. But it is needed to study and characterize the coating tool material when the base metal is in elevated temperature. Hence it is proposed to conduct the experiments with a Zirconium coated HSS flash cutting tool coated using Electron Beam Evaporation and analyzing for the improvement in the performance of cutting tool. The various testing methodology like pin on disc apparatus to measure the friction and wear properties and Scratch Testers to characterize the surface mechanical properties of thin films and coatings, e.g. adhesion, fracture and deformation thicknesses of thin films. This study aimed at the analysis of the wear, thermal and friction of cutting tools using various parameters. The experiment results will be analyzed for the suitability of the coated tool for the improved flash removal operation and tool life.

Keywords: HSS butt weld, Zirconia, Flashcutting tool

INTRODUCTION;
Flash butt welding is one of the resistance welding processes employed to join metals. In flash butt welding process, the ends of the piece to be welded are connected to the secondary circuit of a transformer, while one piece is held firmly by a clamping device attached to a stationary platen; the other piece is clamped to a movable platen. The surfaces to be welded are allowed to touch when heavy currents pass through the peaks or asperities of the edges providing resistive heat to the edges. These asperities start melting and, at greater velocities, the molten bridges are broken and thrown off as flash particles from joint.

Steps involved in flash butt welding process
Clamping
Retraction
Apply current & flashing
Upset & current cut off
Declamping

In butt welding the joints are heated near to the melting temperature of the material and a heavy pressure is applied to fuse the edges together. The metal near to the joint will be in plastic stage. So during upsetting the metal oxides & plastic metal which is near to the weld joint is squeezed out of the base metal and projects outside base metal.
Widely used materials and compositions cutting tool:

Tool steels - low end of scale. Used to make some drills, taps, reamers, etc. Low cost equals low tool life.

High speed steel (HSS) - can withstand cutting temperatures up to 900 K used to manufacture drills, reamers, single point tool bits, milling cutters, etc.

Cobalt - one step above HSS, cutting speeds are generally 25% higher.

Carbides - Most widely used cutting tool today. Basic composition is tungsten carbide with a cobalt binder.

Ceramics - Contain pure aluminum oxide and can cut at two to three times faster than carbides.

Cubic Boron Nitride (CBN) - This tool material maintains its hardness and resistance to wear at elevated temperatures and has a low chemical reactivity to the chip/tool interface. It is typically used to machine hard aerospace materials. Industrial Diamonds - diamonds are used to produce smooth surface finishes such as mirrored surfaces.

Factors influencing the characteristics of coated cutting tool

Hardness
Wear Resistance
Surface Lubricity
Oxidation Temperature
Anti-Seizure

Currently used coating materials over HSS:

- WC/C coatings by physical vapour deposition (PVD) on high speed-steel (HSS)
- TiAlN coatings on high-speed steel (HSS) drill bits, silicon and mild steel substrates using a four-cathode reactive direct current (DC) unbalanced magnetron sputtering system.
- Titanium nitride (TiN) films on high-speed steel (HSS) by using cathodic arc physical vapour deposition (CAPVD) technique.
- Chromium aluminium nitride (Cr–Al–N), titanium nitride (Ti–N), titanium aluminium nitride (Ti–Al–N) and chromium nitride (Cr–N) coatings on 6.35 mm HSS drills.
PVD TiN/TaN multilayer coatings with three different multilayer periods (thickness of one TiN lamella together with one TaN lamella) of 10, 50 and 200 nm thickness on high speed steel substrates.

carbide phase in a new high-speed steel (HSS) substrate and coatings deposited by a physical vapour deposition (PVD) method.

All the above techniques have been carried out regarding cutting tool coating where the base metal is at room temperature.

Proposed Coating material and technique: ZIRCONIA

Zirconia is an extremely refractory material. It offers chemical and corrosion inertness to temperatures well above the melting point of alumina. The material has low thermal conductivity. It is electrically conductive above 873 K and is used in oxygen sensor cells and as the susceptor (heater) in high temperature induction furnaces. With the attachment of platinum leads, nernst glowers used in spectrometers can be made as a light emitting filament which operates in air.

Pure zirconia exists in three crystal phases at different temperatures. At very high temperatures (>2643 K) the material has a cubic structure. At intermediate temperatures (1443 to 2643 K) it has a tetragonal structure. At low temperatures (below 1443 K) the material transforms to the monoclinic structure. The transformation from tetragonal to monoclinic is rapid and is accompanied by a 3 to 5 percent volume increase that causes extensive cracking in the material. This behavior destroys the mechanical properties of fabricated components during cooling and makes pure zirconia useless for any structural or mechanical application. Several oxides which dissolve in the zirconia crystal structure can slow down or eliminate these crystal structure changes. Commonly used effective additives are MgO, CaO, and Y₂O₃. With sufficient amounts added, the high temperature cubic structure can be maintained to room temperature.

<table>
<thead>
<tr>
<th>Thermal Conductivity (W/m.K)</th>
<th>1.8-2.2</th>
<th>1.7</th>
<th>0.69-2.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Heat (J/Kg.K)</td>
<td>400</td>
<td>502</td>
<td></td>
</tr>
</tbody>
</table>

Key Properties of Zirconium Oxide:

Use temperatures up to 2673 K.
High density
Low thermal conductivity (20% that of alumina)
Chemical inertness
Resistance to molten metals
Ionic electrical conduction
Wear resistance
High fracture toughness
High hardness
Table 1: Mechanical properties of zirconia

<table>
<thead>
<tr>
<th></th>
<th>Partially stabilised</th>
<th>Fully Stabilised</th>
<th>Partially stabilised (plasma sprayed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g.cm$^{-3}$)</td>
<td>5.7</td>
<td>5.56 - 6.1</td>
<td>5.6-5.7</td>
</tr>
<tr>
<td>Hardness Knoop (GPa)</td>
<td>10-11</td>
<td>10-15</td>
<td></td>
</tr>
<tr>
<td>Modulus of Rupture (MPa)</td>
<td>700</td>
<td>245</td>
<td>6-80</td>
</tr>
<tr>
<td>Fracture Toughness (MPa.m$^{-1/2}$)</td>
<td>8</td>
<td>2.8</td>
<td>1.3-3.2</td>
</tr>
<tr>
<td>Youngs modulus (GPa)</td>
<td>205</td>
<td>100 -200</td>
<td>48</td>
</tr>
<tr>
<td>Poissons ratio</td>
<td>0.23</td>
<td>0.23-0.32</td>
<td>0.25</td>
</tr>
<tr>
<td>Thermal expansion (10$^{-6}$/K)</td>
<td>8-10.6</td>
<td>13.5</td>
<td>7.6-10.5</td>
</tr>
</tbody>
</table>

Typical Uses of ZrO2:

- Precision ball valve balls and seats
- High density ball and pebble mill grinding media
- Rollers and guides for metal tube forming
- Thread and wire guides
- Hot metal extrusion dies
- Deep well down-hole valves and seats
- Powder compacting dies
- Oxygen sensors
- High temperature induction furnaces susceptors
- Electric furnace heaters over 2273 Kin oxidizing atmospheres

PHYSICAL VAPOUR DEPOSITION - ELECTRON BEAM EVAPORATION

Metal vapor plasma is produced by melting the desired metal in a crucible using a focused electron beam source. The coating is produced when the metal vapor ions react in a
low pressure gas. The electron beam source allows for electron heating of the substrate material when a positive potential is applied. The electron beam can be used to ionize argon gas to enhance sputter etching of the substrate when a negative charge is applied.

The EB-PVD process takes place in a vacuum chamber consisting of a vacuum-pumping system, horizontal manipulator, a water-cooled crucible containing a ceramic ingot to be evaporated, an electron-beam gun, and the work piece being coated. The electron-beam gun produces electrons, which directly impinge on the top surface of the ceramic coating, located in the crucible, and bring the surface to a crucible.

Vapor Cloud Substrate temperature high enough that vapor steam is produced. The vapor steam produces a vapor cloud, which condenses on the substrate and thus forms a coating. The substrate is held in the middle of vapor cloud by a horizontal manipulator that allows for height variation in the chamber. During the coating process, oxygen or other gases may be bled into the vapor cloud in order to promote a stoichiometric reaction of ceramic material. An over source heater or an electron beam gun may be used for substrate heating, which keeps the substrate at a desired temperature.

Fig 1: Electron Beam Evaporation

The primary control variables for the coating process are the ingot feed rate, ingot size, gun current, and over source heater power. The feed rate and size controls how much mass is to be evaporated by the gun current. The gun current controls how much power is transmitted to the melt pool, and thus controls melt pool temperature for the evaporation rate and deposition rate. The maximum gun current is limited by the stability of the ingot melt surface. Too high a current overheats the ingot.
surface causing spattering, thus losing mass evaporated. The melt pool is a major source of heat energy for the substrate as well as substrate heating if used. The substrate temperature is important because it controls many of the deposited coatings material properties.

A source of substrate heating that is uncontrollable is the time in the coater. As parts are coated, ceramic coating builds up on the chamber walls changing the heat dynamics of the chamber, thus effecting substrate temperature. Therefore, chamber temperature varies depending on when the coating chamber was last cleaned. Overall, substrate temperature is hard to control in the coating process. The coating operator must control the primary variables involved in the coating process, as well as beam sweep frequency and rotation rate, which are set prior to the coating process. Beam sweep frequency refers to the irregular scanning pattern the electron beam gun makes on the ingot surface.

**TESTING:**

**Pin on disc tester**  
The pin on disc tester measures the friction and sliding wear properties of dry or lubricated surfaces of a variety of bulk materials and coatings. The pin on disc tester consists of a rotating disc of the material to be tested against a stationary sphere, usually made of cemented carbide, referred to as the pin. Most pin on disc testers are computer controlled and store the measured friction versus time or distance plots for future reference.

**Scratch tester**  
Scratch Testers are dedicated instruments for characterizing the surface mechanical properties of thin films and coatings, e.g. adhesion, fracture and deformation.

**Dilatometer**  
It is an instrument that measures coefficient of thermal expansion i.e. dimension variations of a specimen heated at temperatures that generally range from 25 to 1673 K.

**Nanoindentation**  
Indentation tests, sometimes called Hardness tests, are the most commonly applied means of testing the mechanical properties of materials. **Scanning electron microscope (SEM)**  
The scanning electron microscope (SEM) is a type of electron microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties such as electrical conductivity.

**Transmission electron microscope (TEM)**  
Transmission electron microscopy (TEM) is a microscopy technique whereby a beam of electrons is transmitted through an ultra thin specimen, interacting with the specimen as it passes through. An image is formed from the interaction of the electrons transmitted through the specimen; the image is magnified and focused onto an imaging device, such as a fluorescent screen, on a layer of photographic film, or to be detected by a sensor such as a CCD camera. TEMs are capable of imaging at significantly higher resolution than light microscopes, owing to the small de Broglie wavelength of electrons. This enables the instrument's user to examine fine detail—even as small as a single column of atoms, which is tens of thousands times smaller than the smallest resolvable object in a light microscope.
Experimental Results and Analysis:

Figure 1 shows data for the average thermal conductivity of all six coated specimens. The uncertainty bars shown are for a 20 % relative standard uncertainty. The combined standard uncertainty of the apparatus is 5 %. However, the apparatus was designed for measuring monolithic ceramic materials of greater thickness. Due to the inherent interfacial thermal resistance between the sensor plates and the specimen, the reliability of the measurement is influenced by the ratio of the thermal resistance due to the specimen and the thermal resistance of the contact between the specimen and sensor plates. In general, the thermal resistance due to the specimen should be at least four times greater than that of the interfacial thermal resistance between the specimen and sensor plates. However, the small thicknesses of some of the
specimens results in a low thermal resistance of the coatings relative to that of the specimen/sensor-plate interface. This factor significantly increases the uncertainty of the measurement of thermal conductivity of the coating vs temperature.

**Conclusion and Future work:**
The average thermal conductivity was measured over temperatures ranging from approximately 100 °C to 900 °C. The measured results vary from 1.5 W·m⁻¹·K⁻¹ to 1.7 W·m⁻¹·K⁻¹ with a relative uncertainty range of 20 % at each temperature. The results are relatively independent of temperature. Due to the fine microstructure and porosity of yttria-stabilized EB-PVD coatings, the thermal conductivity is expected to be independent of temperature. Even though EB-PVD coatings grow in a directional manner, resulting in a high degree of texture, they do not exhibit thermal behavior normally associated with texture. Figure 2 is an SEM image of an EB-PVD coating showing fine structure, which promotes geometric scattering of phonons. Measurements on similar coatings show a three-level structure of porosity that can result in significant reduction of thermal conductivity from that of sintered polycrystalline material. The large amount of scattering due to the disorder of the stabilized zirconia lattice, combined with the geometric scattering due to a large population of other defects causes these coatings to have a lattice thermal conductivity that is not sensitive to temperature.

**REFERENCES:**