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Study of wettability test of pure aluminum against uncoated and coated carbide inserts

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ABSTRACT

The wide application of aluminum in different industries has increased the need for finding the suitable cutting tool. In contrast to ferrous materials, the dry machining of aluminum is a great challenge. Wetting test is widely used to find out the chemical affinity of aluminum with different tool materials before proceeding for actual machining. Wettability tests were carried out in a high vacuum brazing chamber to find out the spreadability of aluminum on cutting tools. Mono or multilayer coated carbide tools with a top coating of TiC, TiN, Al_2O_3, TiB_2, MoS_2 and diamond on cemented carbide (WC–Co) cutting tool inserts were used in the experiment. The results revealed that diamond/graphite is the most inert for aluminum.

1. Introduction

Metal–ceramic interface plays a vital role in different industrial applications such as light bulbs, micro-electronic components and medical implants. The studies on mechanism of bond formation at the interface of metal and ceramic were carried out by various research groups. This is reflected by increasing number of experimental and theoretical studies by them. The progress in this area has been particularly rapid in recent years. This is due to more refined experimental techniques that are available to explore the interface atomic and electronic structures [1,2].

Wettability and reactivity determine the quality of bonding between the constituents and thereby greatly affect the final properties of the composite material. Various uncoated and coated tools are used for machining ferrous materials [3]. The great demand of non-ferrous materials in various applications has replaced the use of ferrous materials. Hence machining non-ferrous materials is a great challenge. Different research groups have carried out wetting tests before going for actual machining. Coating of TiN, TiC, TiB_2, Al_2O_3, MoS_2 and diamond on cemented carbide (WC–Co) insert, were used in wetting of aluminum in a high vacuum brazing furnace. The interface results confirm that diamond/graphite has the highest non-wetting characteristics.

The complex interfacial bond formation at the interface of aluminum and ceramic tool can be predicted by work of adhesion (W_{ad}). This is defined as the bond energy needed per unit area to reversibly separate the interface into two free surfaces neglecting plastic and diffusional degree of freedom.

$$\gamma_{SV} - \gamma_{SL} = \gamma_{LV}\cos\theta \quad (1)$$

where γ_{SV} energy between solid and vapour

γ_{SL} energy between solid and liquid
γ_{LV} energy between liquid and vapour
θ is the angle of contact

For a given system, the value of the contact angle may change due to various reasons. Among these the most critical is wetting hysteresis due to surface roughness, experimental parameters and segregation/reaction of impurities on alloying elements. The thermodynamic work of adhesion (W_{ad}) is an important thermodynamic parameter characterizing the wetting/bonding between two materials. It can also be correlated to the mechanical strength of a joint as a nominal part of the interfacial fracture energy.

The work of adhesion equals to the work of creating (equilibrated) liquid–vapour and solid–vapour interfaces from a liquid–solid interface, as expressed by the Dupre's equation:

$$W_{ad} = \gamma_{SV} + \gamma_{LV} - \gamma_{SL} \quad (2)$$

From Eqs. (1) and (2)

$$W_{ad} = \gamma_{LV}(1 + \cos\theta) \quad (3)$$

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The chemical affinity of each element present at the metal–ceramic interface makes the compound complex. Various new methods are adopted by many investigators to understand the mechanism of formation of bonding at the interface. Some of those are density of state (dos) at the Fermi level, X-ray analysis, EDAX, cohesive and adhesive energy of each element/phase.

Transitional carbides/nitrides/oxides are used in various applications. One of the major uses is its coating on cutting tool for machining various materials. These high temperature resistant materials are less sensitive to oxidation. These materials have a high chemical affinity towards a number of metals (compound) at very low temperature [4].

Ferrous metals such as aluminum, copper, silver and gold having FCC structure are ductile in nature. When ceramic materials come in contact with these materials, there develops a strong tendency in the formation of bond, which leads to chemical adhesion at the interface. The chemical bonding leads to formation of stoichmetric and sub-stoichmetric phases. Different bond energy resulting from the bonding of M–C, C–C and M–M are expressed to understand the availability of energy for chain reaction [5,6].

2. Experimental procedure and conditions

2.1. Wettability tests

Nature of affinity or inertness was assessed by wettability test, solid-state diffusion couple test, tribological test, keeping the materials under consideration as the tribo-pair. However, aluminum wettability test can be considered to be very reasonable way of assessing its expected affinity or inertness towards another material. It has already been studied that because of low melting and softening point, aluminum may attain melting stage at high speed machining.

Table 1 shows the solid surfaces used for wettability tests. The nominal dimensions of the solid block were 12.7×12.7×3.76 mm. Cylindrical pure rolled aluminum specimen used in wettability test was of dimension Ø3×3 mm and was produced by machining. Test specimens were cleaned ultrasonically with trichloroethylene followed by 2-propanol.

Wettability test was conducted under high vacuum ($\approx 1\times10^{-5}$ Torr). The aluminum cylinder was first placed on the solid specimen block with its axis vertical. The pair was then placed on the horizontal graphite block of the vacuum furnace as shown in Fig. 1. The graphite plate acted as a resistive heater in the vacuum furnace. The melted mass of cylindrical aluminum piece had acute or obtuse wetting angle depending on the substrate conditions.

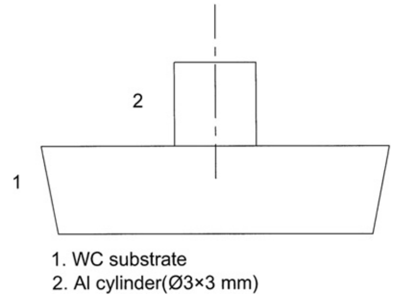

Fig. 1. The placing of substrate and the aluminium specimen during wetting experiment.

Table 1
Various solid surfaces used for wetting test.

Sl.No	Solid surface	Remarks
Tool 1	Sandvik SPGN 120308 K10 carbide insert	As received WC-94% and Co = 6%
Tool 2	Sandvik SPGN 120308 K10 carbide insert	Pretreatment with Treat 1 HCl + HNO_3 + H_20 (1:1:1) for 15 min Co = 0.42%
Tool 3	Sandvik SPGN 120308 K10 carbide insert	Pretreatment with Treat 2 $K_3[Fe(CN)_6]$ + KOH + H_20 (1:1:10) for 15 min Co = 15.5%
Tool 4	CVD TiC coated carbide insert	Interlayer
Tool 5	CVD TiN coated carbide insert	Interlayer
Tool 6	CVD Al_2O_3 coated carbide insert	Interlayer
Tool 7	PVD TiB_2 coated carbide insert	Interlayer
Tool 8	MoS_2 spray coated and resin bonded	After spraying, the coated specimen was vacuum baked at 1×10^{-5} Torr pressure and 200 °C for 2 h to increase adhesion of MoS_2 coating with the substrate
Tool 9	Graphite	Procured from Graphite India Ltd.
Tool 10	Diamond coated carbide insert	HFCVD in our own reactor (thickness ≈ 6 μm)

2.2. Procedural steps for wetting tests

The test specimens were directly placed on the graphite heating plate and then the stainless steel bell jar was placed on the base plate of the furnace tightly. The schematic view of the high vacuum furnace and other details are shown in Fig. 2. The transformer was switched on for heating the graphite heater. Constant heating rate was maintained throughout the processes. The heating started after the chamber pressure had reached 1×10^{-5} Torr by combination of rotary and diffusion pumps. This order of vacuum was obtained with liquid N_2 trap in the pumping line. The thermocouple tip was placed on the graphite block. The insert and aluminum block were heated slowly (≅40 °C/min) to 800 °C. This temperature was selected to counteract loss due to heat transfer inside the chamber. At this temperature aluminum (Al) and substrate block were kept for 5 minutes to ensure attainment of a steady state wetting for all specimens. The system was then allowed to cool down to 80 °C naturally under high vacuum and the specimens were taken out. The changes in shape of the aluminum cylinder were observed through front glass window.

2.3. Characterization of the wetting samples

The aluminum specimen and tool substrate were preserved for analysis in SEM (Model JEOL and JSM-5800, Japan, voltage: 20 KV, resolution: 50 Å), which was attached with EDAX(Energy Dispersive Analysis of X-ray). The SEM micrographs and EDAX spectra of the carbide inserts, pretreated with Treat 1 and Treat 2 respectively were observed earlier [7,8].

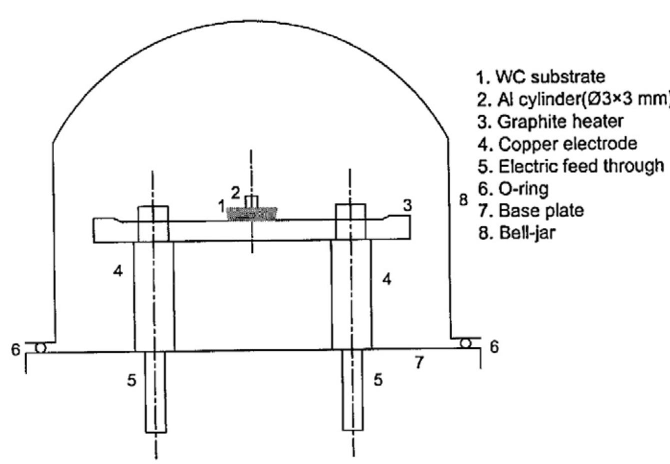

Fig. 2. The schematic view of the high vacuum furnace and other details.