DEVELOPMENT OF BRAZED MICRO DIAMOND PENCIL GRINDING TOOL USING LOW TEMPERATURE FILLER ALLOY

ABSTRACT

The primary focus of this study involves two pivotal aspects: first, the thorough analysis and characterization of a low-temperature brazed filler alloy; second, the development and characterization of a brazed diamond pencil grinding tool. Preceding these endeavors, the high vacuum furnace, and the micro-grinding center (MGC) have been developed. These advancements were crucial as they serve as foundational equipment essential for both developing and characterizing the brazed diamond pencil grinding tool.

In the past decades, the demand for ceramic microparts with micro- and nano- scale features has continuously grown due to their high strength, wear resistance, and good chemical stability. These ceramic microparts and miniaturization trends have influenced various industrial applications (i.e., precision ceramic bearings in EDM spindle for electrical isolation, ceramic nozzles, fuel injectors, customized ceramic shaft, rings for thermal isolation in aerospace application, etc.) and medical devices (i.e., dental implants, orthopedic implants, biomimetic scaffold for bone-tissue regeneration etc.). The machining of ceramic materials is challenging due to their high hardness, fracture strength and fracture toughness. Grinding is preferred over traditional machining methods for achieving final dimensional accuracy due to its abrasive nature. These abrasives gradually remove the material in tiny chips, reduce the risk of unintended surface damage, increase tool life, and contribute to achieving precise dimensional accuracy and producing a smoother surface. Additionally, apart from process parameters, grinding wheels with different sizes of grit, protrusion, grit density, and bond material enhance the reliability of the grinding process in achieving the desired dimensional accuracy. To address this, the demand for development of micro- diamond pencil grinding tools has gained tremendous importance in tool manufacturing industries. A successful development of these tools requires joining diamond grits to carbide surface firmly. There are different types of braze filler alloys available for the joining of the diamond such as Ni-based, Cu- based and Ag-based. The majority of the Ni-based and Cu-based filler alloy literature observed the graphitization of the diamond as the brazing temperature of the filler alloy exceeds 1000 °C. The graphitization of diamond results in an immediate loss of grit sharpness in grinding wheels during its application. Ag-based filler alloys are the most commonly used by many researchers for brazing diamond grits. These filler alloys have a moderate melting point, good strength,

toughness, and corrosion resistance. In addition, the ductility of Ag and Cu is reasonably good, and the plastic deformation of the filler layer could lower the interface stresses as well.

During brazing of diamond, the active elements such as Ti, Cr, V, Hf, etc., in the braze filler alloy form stable oxides (i.e., TiO_2, Cr_2O_3, V_2O_5, and HfO_2) prior to reaching brazing temperature, which diminishes the bonding characteristics of the braze alloy. To prevent such transformation, the brazing of diamond has been carried out in a high vacuum environment. In the present thesis, prior to brazing application the high vacuum brazing furnace has been developed in the Automation laboratory, Mechanical Engineering Department, IIT Delhi. The design criteria for the development of the vacuum chamber, selection of the vacuum pumping system, selection of resistance heating element, FE-modelling and simulation of single-layered and multi-layered radiation shield, and integration of the high vacuum furnace have been described in details. The results show the time required to achieve less than 10^{-5} mbar is less than 2000 seconds and the power required to reach 1000 °C is less than 1 kW.

Furthermore, to perform the micro-grinding operation the micro-grinding center has also been developed at the Automation laboratory, Mechanical Engineering Department, IIT Delhi. This includes the early-stage design steps, and assembly of a micro-grinding center (MGC) with integrated multiprocess micromachining tools. MGC is the integration of the three different machining tool heads: primarily high-speed spindle for micro-grinding/milling operations, in addition, dry micro-electric discharge machining, and micro-laser beam machining have also been integrated on a single setup. The design of the machine tool base and other components have been carried out and analyzed under static load conditions before the manufacturing and assembly.

The primary work of the thesis start with the thorough analysis and characterization of a low-temperature brazed filler alloy: Ag-Cu-24.3In-3Ti active alloy (Incusil-ABA), for the joining of diamond grits to WC-cermet surface via brazing route. Analysis showcases that the titanium present in the alloy has been found to segregate towards diamond-alloy interface. It was expected that such segregation would ensure a proper wetting by the alloy. The presence of Indium element, act as melting point depressant, that reduces the braze temperature of the alloy. However, the overall morphology of the brazed joint has revealed that improper melting and poor wetting by alloy on cermet surface have been the two major challenges. Experimental findings of this investigation indicate that both brazing temperature and dwell time have significant influence on microstructure and other related properties of the alloy. The current study showcases that a careful control on brazing temperature and dwell time demonstrates a remarkable improvement in wetting characteristics and alloy morphology. It has been observed

that a brazing temperature of 780 °C and dwell time of 15 minutes resulted in a good brazed joint morphology. The study also investigated the effect of said brazing temperature on grits physical characteristics using Raman spectroscopy. At the end, scratch test and wear characteristics of the filler are investigated in detail.

In continuation, single-layer brazed diamond tools have been developed using the same filler alloy. Different micro-diamond pencil grinding tools (μ-DPGT) have been developed at two different brazing temperatures at 750 °C and 780 °C for the dwell time of 15 minutes. The performance of the developed μ-DPGT tools have been evaluated via grinding on partially stabilized zirconia. The tool life has been analyzed after long cycle grinding of 1200 mm for the two different depth of cut 3 μm and 6 μm and the same has been compared with electroplated tool. A detailed analysis is presented to address the suitability of Indium based active Ag-Cu filler in the light of the grinding force and grit retention ability of the tools. Radial tool wear has been measured employing indirect profilometry. Diamond grits of μ-DPGT and electroplated tools have been observed under SEM to identify and characterize various modes of diamond grit wear. This analysis not only highlights some unreported modes of wear of diamond grits but also illustrates and describes their mechanisms while grinding of advanced ceramics. During the grinding of advanced ceramics using diamond grinding tool, it has been observed that the abrasion is the primary wear mechanism of the diamond grits. No trace of wheel loading has been observed in μ-DPGT tool due to the higher grit protrusion. The wear-flat of the grits have been observed, and the main cases of the wear has been observed as two-body abrasion and consequent grit failure from the bond. In the case of electroplated tool, wheel loading and rubbing with bond material have been observed. Furthermore, wear-flat, indentation fatigue fracture due to mix-body abrasion and consequent grit pullout has been found to be the dominant mode of diamond grit wear. The physical characteristics of diamond grits have been examined with Raman spectroscopy which revealed graphitization of some of the active diamond grits in electroplated tool.

The outcome of this investigation will be of immense interest to tool manufacturing industries associated with development of brazed micro-pin diamond grinding tools using alloys having low melting point, high vacuum furnace manufacturing industries associated with the development of brazed diamond grinding tools and machine tool manufacturing industries associated with conventional and non-conventional machining centers.

Keywords: Incusil-ABA, Diamond, wetting angle, brazing temperature, micro-grinding, machine tool development