ABSTRACT

The requirement of joining materials having dissimilar nature is unavoidable since new materials are invented having unique and varying properties. Researchers have studied the nature of joining dissimilar materials and it is found that the issues lie in varying properties such as thermal expansion coefficient, crystalline nature, thermal fatigue etc.

Aluminum to magnesium alloy joining has wider applications in automobile and aerospace industries due to the specific weight of the two alloys along with other properties. However, direct joining of aluminum to magnesium alloy is not possible due to the formation of intermetallic compounds at their interface. Copper (Cu) to stainless steel (SS) joining is another combination which has applications in electrical and refrigerator industries due to the high electrical and thermal conductivity of copper and good corrosion resistance of stainless steel. However, Cu to SS joining has many defects in fusion joining process. Its joining is limited due to high cost joining processes with stringent conditions. Another combination where the high cost of the joining process makes the cost of the joint assembly very high is cBN to WC-Co which is widely used in machining of high hardness materials and superalloys, especially ferrous alloys.

Thus, there is a need to solve the problem of joining of dissimilar materials in a cheap, energy-efficient and environment-friendly manner. A relatively new process of heating called the microwave hybrid heating can be employed to join dissimilar materials. This process makes the use of high microwave absorbing materials called susceptors to enhance the joining process. Microwave hybrid heating has been used in the past in sintering of ceramics, metals and composites. More recently, it has been used in melting and joining of bulk metallic materials.
The joining of AA6061 to AZ31B; oxygen free copper to stainless steel (SS304); and cBN to WC-Co through microwave hybrid heating is investigated in this study. The simulation of heating of different susceptors and joining by interlayer are studied with the help of COMSOL multiphysics software. Further, the use of different susceptors, interlayer compositions, metal powder sizes etc. are investigated.

Simulation of microwave heating of three different susceptors i.e. SiC, activated charcoal and graphite in a multimode microwave oven is carried out. As the size of the SiC susceptor increases from 38 mm to 44 mm, the temperature of the surface goes from 191 ºC to 246 ºC for 5 minutes of microwave time. The maximum surface temperature simulated for 5 minutes of microwave exposure time on SiC, activated charcoal and graphite are 191 ºC, 363 ºC and 435 ºC. The experiments are in agreement with the simulation, concluding that the fastest heating resulted when graphite is used as a susceptor material. Subsequently, graphite is used as a susceptor to simulate the joining of copper to stainless steel. Experiments were performed initially for joining of AA6061 to AZ31B since they have a low melting point (~650 ºC). Nickel metal powder was used as an interlayer to join AA6061 to AZ31B. Due to the very high melting point of Ni, it was not possible to prevent the formation of Al-Mg intermetallic compounds. The heat at the interlayer was sufficient to melt the substrate surface adjacent to it before the Ni powder could form a uniform barrier between the substrate materials. The joining of AA6061 to AZ31B was possible when Ag-Cu-Ti alloy and zinc were used as interlayer materials. Ag-Cu-Ti alloy interlayer formed MgAlzO4, Al60Mg38Ag2 and Mg55Al40Ag5 intermetallic compounds due to which the joint of low strength (9.12 MPa shear strength) is obtained. Zinc interlayer forms a eutectic reaction between the Zn interlayer and AZ31B, leading to the formation of Mg solid solution and MgZn phase. Thus, Zn interlayer is successful in preventing the formation of Al-Mg intermetallic compounds and is the most suitable interlayer. It is also concluded that activated charcoal susceptor is preferred for slow uniform
heating whereas graphite susceptor is preferred for rapid heating. Copper and nickel interlayer are successful in joining of oxygen free copper (OFC) and stainless steel through microwave hybrid heating. With a decrease in particle size, the heating rate increases and the porosity at the interlayer also decreases. The shear strength of the joint using 4 μm Cu powder interlayer is 83.12 MPa for 14 minutes of microwave exposure time. No brittle and hard intermetallic compound is formed when Cu is used as interlayer however when Ni is used as an interlayer, a solid solution of Ni-Cu is formed and FeNi₃ is formed between SS304 and Ni interlayer.

Joining of cBN to WC-Co by Ag-Cu-In-Ti alloy is successful by using microwave hybrid heating, with an inert environment. Titanium diffuses towards cBN to form TiN, TiB₂ and TiB (confirmed by XRD and EDS) which aids in wetting by braze alloy. The joint fractures along the cBN (parent material) while performing shear strength test, depicting the joint is stronger than the parent material. This process can be used to increase productivity by up to 70%.

The role of microwave hybrid heating process and selection of susceptors for joining dissimilar materials having a wide variety of melting point ranging from 600 ºC to 3000 ºC is elucidated. The simulation of microwave heating of susceptors and microwave joining of OFC to SS304, is in agreement with the experimental result. Activated charcoal is a suitable susceptor, for joining AA6061 to AZ31B and similar low melting alloys due to uniform heating and controlled heating behaviour of activated charcoal. In order to join OFC to SS304 and for joining similar high melting alloys, graphite is the best suited susceptor, due to rapid heating. A mixture of graphite and activated charcoal may be used when fast heating as well as uniform heating is required for joining of dissimilar materials as has been successfully demonstrated in cBN to WC-Co joining. This novel approach for successfully brazing cBN to WC-Co with an alternative inexpensive process i.e. microwave hybrid heating has been developed.