Characterization of Diffusion Welded Joints between Titanium and Permendur Type Alloy Using Different Interlayers

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Abstract

The experiments regarding the solid–state diffusion bonded joints prepared between commercially pure titanium and permendur type soft magnetic alloy are presented. The diffusion bonding of these materials were carried out using copper and nickel interlayers, in the temperature range of 850-950 °C for 1,5 hrs., under uniaxial pressure, in argon atmosphere.

The microstructure of the transition joints were revealed by optical microscopy and the presence of different intermetallic compounds at the interface were examined by X-ray diffraction.

The technological parameters which led to good jonctions for the studied systems were also specified.

1. Introduction

The increasing trend in making monolithic joints between dissimilar materials put forward the need for a high precision joining technique such as diffusion bonding, in order to exploit the individual properties of these materials. Mechanical joining or traditional fusion welding of dissimilar materials promotes different problems such as distortion of components, formation of stress-concentration sites, and development of chemical heterogeneities, which ultimately result in crevice corrosion or fatigue failure during service [1].

Diffusion bonding of commercially pure titanium and FeCoV soft magnetic alloy reported in this study, has emerged as an improved fabrication technique for application in dentistry. From this particular dissimilar joint, a dental implant-keeper is made to be used together with a dental magnetic attachment in order to secure the dental prosthesis by a strong magnetic attractive force.

An example of holding dental prosthesis to the mandible by means of magnets is presented in Fig. 1, [2]. The attractive force acts between a dental magnetic attachment (4) in a denture (1) and a keeper (5) made from a soft magnetic material embedded in a root cap (6) inserted into a tooth root (7). The denture has artificial teeth (2), a resin base (3) and a dental magnetic attachment (4). When the dental magnetic attachment is set on the keeper, a closed magnetic circuit composed from the permanent magnet, i.e.Nd-Fe-B type of Sm-Co type rare-earth magnets, and the yoke (both included in the magnetic attachment) and the keeper, is formed.

It is preferred to use various anticorrosive dental magnetic materials which have greater than 1.3 T of saturation magnetic flux density and magnetic permeability greater than 3000. Such magnetic materials are Fe-Cr-Mo alloy, and soft magnetic stainless steel, such as 19Cr-2Mo-0.2Ti steel, 17Cr-2Mo-0.2Ti steel, etc. [2]-[4].

The dental implant-keeper fabricated in this work, is a monolithic joint between a biocompatible material (Ti) and a soft magnetic alloy (FeCoV), obtained by diffusion welding technique.

Up to this report, there is no information concerning diffusion bonding of pure Ti and FeCoV alloy obtained by direct bonding or using intermediate layers.

It has been reported by researchers [1], [5], [6] and [7], the formation of the intermetallic phases like Fe₄Ti, Fe₃Ti, Fe₃TiₓO, χ, λ and TiC in the diffusion zone of the joint consisting of a Ti/Ti alloy and steel/stainless steel due to limited solubility of Fe and Ti as a function of temperature.

Direct bonding between titanium and stainless steel promotes residual stress at the interface region caused by mismatch of thermal expansions between the bonding materials and, also leads to the formation of brittle intermetallics in the diffusion zone, [8] and [9].
The use of appropriate intermediate materials can minimize formation of the brittle intermetallics which in turn further increases the strength properties of the diffusion-bonded joint.

Copper can be considered as a potential candidate to be used as interlayer to improve the joint quality. Copper does not form any intermetallics with iron. Moreover, the melting point of copper is lower with respect to Ti, Fe and Ni; so, increase in the flowability of the same at higher temperature (> 0.5 Tm, Tm – the melting point in K) will encourage a good contact between the faying surfaces. Though binary phase diagram of Cu-Ti indicates the occurrence of Cu₂Ti, Cu₃Ti₂, CuTi and CuTi₂ with increasing Cu content, however, improved contact area may have some beneficial effect on the bond strength of the diffusion-welded joints [10].

Nickel has substantial solid solubility in iron and Kamat at all reported that a nickel – stainless steel diffusion couple is free from intermetallics [11].

The present study reveals the preliminary results focusing attention on the characteristics of the diffusion zone of the FeCoV/Ti bonded specimens as a function of processing temperature under uniaxial pressure, using copper and nickel as intermediate layers.

2. Experimental

The cylindrical samples of pure commercially Ti and Fe-48Co-2V (wt %) soft magnetic alloy (Permendur) with the dimensions of 5 mm diameter both for Ti and Permendur and 6 mm length for Ti and 11 mm length for Permendur respectively, were used for diffusion couple preparation.

Permendur alloy was elaborated in a vacuum melting furnace of Leybold-Heraeus type using elemental metals (Co and Fe), and FeV78.65 pre-alloy. The melting temperature was T ≅ 1600 °C and the melting time was t = 10 min. This casted FeCoV alloy was subjected to a heat treatment for homogenising at 850°C/2h, in Ar atmosphere.

The mating surface of the cylinders was prepared by conventional grinding and polishing techniques. The copper foil (40 μm thick, 99.95 purity) and nickel foil (50 μm thick, 99.95 purity) were used as intermediate materials after cleaned in acetone and dried in air. The Ti-Cu-Permendur assembly was kept in contact in a fixture and was inserted in a furnace, in argon atmosphere. The Ti-Ni-Permendur assembly was prepared for diffusion bonding in the same way. The diffusion bonding was carried out at 850, 900 and 950 °C for 1.5 h in argon atmosphere. Uniaxial pressure was applied along the longitudinal direction of the samples by the means of the fixture used. Heating was done at a constant rate of 5 °C/min at the time of processing and samples were allowed to cool in argon.

The diffusion bonding joints thus formed were cut transversally and prepared by usual techniques for metallographic observation. The diffusion bonding zone was observed in an optical microscope and the presence of intermetallic phases in the reaction zone was investigated by X-ray diffraction on the fracture surfaces of the assemblies.

3. Results and discussion

The diffusion bonded assemblies were micro processed to obtain the shape of a preliminary dental implant-keeper with 4 mm diameter, 1.4 mm disc height and 7 mm length, Fig. 2, that can be used to fix a denture to a dental attachment by use of a magnetic force. The diffusion bonding line of the joint of FeCoV-Cu-Ti can also be observed.

To prevent the contact with saliva acids, the ferromagnetic base of the dental implant-keeper have to be coated with a thin layer of TiN.

Figure 2: Ti dental implant-keeper with FeCoV soft magnetic base obtained by diffusion welding technique and micro processing

The obtained FeCoV soft magnetic alloy has the magnetic properties presented in Fig. 3.
attractive force to hold and to stabilize the denture on teeth roots.

The optical microstructure of the FeCoV-Cu-Ti bonded assembly is shown in Fig. 4.

![Figure 4: Optical microscopy image of diffusion bonding area of the Ti-Cu-FeCoV assembly (x 350)](image)

It is observed that, certain amount of diffusion occurs between Cu interlayer and the two dissimilar materials. Ti-Cu interface is characterized by the presence of a lightly reaction zone.

It was settled that beside the presence of Cu-Ti intermetallics, the tensile properties of the transition joints improve substantially in comparison to direct bonding of the same dissimilar materials: hence, it was concluded that embrittlement effect of Cu-Ti intermetallics is lower than Fe-Ti intermetallics, [5], [8] and [9].

Diffusion welding temperature of 900 °C promotes mass transfer of the alloying elements across the interface, which is responsible for the increase in volume fraction of the reaction products; hence, causes more embrittlement to the joints with respect to the couples processed at 850 °C. However, plastic collapse of the mating surface asperities leads to intimate contact, which counterbalances the embrittlement phenomena due to intermetallic phases. Beyond 900 °C diffusion temperature, the width of brittle intermetallics considerably increases and the embrittlement effect over-balances the positive effect obtained due to a better coalescence of the faying surfaces.

Researchers from [5] concluded that the embrittlement effect of Cu-Ti and Cu-Ti-Fe base intermetallics is less with respect to Fe-Ti intermetallic in lowering the bond strength. Despite the presence of brittle reaction products in the diffusion zone, the use of copper as intermediate materials improves the joint quality by eradicating void formation near interface, which was observed by direct bonding of titanium – FeCoV soft magnetic alloy.

The intermetallic compounds in the diffusion zone of diffusion bonding area of Ti-Cu-FeCoV assembly have been evidenced by X-ray diffraction technique and are given in Fig. 5 and 6.

![Figure 5: X-ray diffraction analysis of the fracture surfaces of the FeCoV-Cu-Ti assembly bonded at: 900 °C/1.5 h](image)

At 900 °C, the atomic activity across the mating surfaces increases, providing significant interdiffusion. Besides the Ti phase with hexagonal structure, the intermetallics observed at this temperature were the compounds of Ti2Cu3 (Cu4Ti3) with tetragonal structure and Cu3Ti with orthorhombic structure (Fig. 5). Also, it was revealed the existence of intermetallic compounds of Co3Fe7 (FeCo) with cubic structure (Fig. 6). From the Fe-Co phase diagram, this compound appears around 48-50 at. % Co.

![Figure 6: X-ray diffraction analysis of the fracture surfaces of the FeCoV-Cu-Ti assembly bonded at 900 °C/1.5 h](image)

In fig. 7, the diffusion bonding area of the Ti-Ni-FeCoV assembly is presented.
4. Conclusions

The solid-state diffusion bonding was carried out between commercially pure titanium and FeCoV soft magnetic alloy using 40 μm copper interlayer and 50 μm nickel interlayer, respectively. Bonding was carried out in the temperature range of 850 – 950 °C for 1.5 h under uniaxial pressure in argon atmosphere. The characterization of the transition joints of both studied assemblies reveals the following:

At a lower joining temperature of 850 °C, bond strength is poor owing to incomplete coalescence of the mating surfaces.

By X-ray diffraction it was evidenced the existence of the intermetallic compounds of Ti₂Cu₃ (Cu₄Ti₃) with tetragonal structure, Cu₂Ti with orthorhombic structure and also, the presence of Fe₃Co (FeCo) compounds at the transition joint of FeCoV-Cu-Ti.

For the transition joint of FeCoV-Ni-Ti, the X-ray diffraction revealed the existence of the NiTi intermetallic compounds which has higher plasticity than those of Fe-Ti intermetallic compounds.

At 900 °C, it was obtained the best coalescence of the mating surfaces for the diffusion joints FeCoV-Cu-Ti, while with increasing temperature at 950 °C, the better coalescence was obtained for FeCoV-Ni-Ti diffusion bonded joints.

References