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ARTICLE

# Diffusion Bonding of TiC Cermet to Stainless Steel Using Impulse Pressuring with Ti-Nb Interlayer

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**Abstract:** Impulse pressuring diffusion bonding (IPDB) of TiC cermet to stainless steel 06Cr19Ni10 using Ti-Nb interlayer was carried out in an attempt to reduce the bonding time and to alleviate the detrimental effect of interfacial reaction products on bonding strength. Successful bonding is achieved at 890 °C under a pulsed pressure of 2~10 MPa within a duration of only 4~12 min, which is notably shortened in comparison with conventional diffusion bonding. Microstructure characterization reveals the existence of $\sigma$ phase with a limit solubility of Nb, ($\beta$-Ti, Nb) phase, and solid solution of Ni in $\alpha+\beta$-Ti in the reaction zone. Maximum shear strength of 110 MPa is obtained when the joint is bonded for 10 min, indicating a robust metallurgical bonding is achieved. Upon shear loading, the joints fracture along the remnant Ti/$\alpha+\beta$-Ti interface and extend to the interior of TiC cermet in a brittle cleavage manner. This technique provides a highly promising bonding method of TiC cermet and steel.

**Key words:** TiC cermet; diffusion bonding; impulse pressuring; Ti-Nb; microstructure

TiC cermet is a promising material ascribed to its excellent combination of desirable properties, such as light-weight, high hardness, wear resistance and stability at elevated temperature[1,2]. However, the intensive application of TiC cermet is restricted, primarily due to its low fracture toughness and poor workability originated from its inherent brittleness. A promising option to take advantage of the good characteristics of cermets is to combine it with metallic structure on selected regions, generally steel.

Successful joining between TiC cermets and steel encountered two key obstacles: one was the chemical inertness of TiC cermet, while the other was their mismatch of thermal expansion coefficient (CTE) which led to high residual stress [3-5], and consequently formed mechanical weak joint. Conventional fusion welding was infeasible in the case of dissimilar materials joining of refractory TiC cermet (～3067 °C) [6] to steel owing to their different melting points, and would result in concentration of residual stress at the joints [7]. Diffusion bonding, by contrast, has been demonstrated to be one of the most practicable methods to effective bond ceramics to steels.

Diffusion bonding appeared as a near net shape forming processing which can be used for preparation of heat resistant joint at much lower temperature than conventional connection methods [8, 9]. This bonding process was even easier using multilayer soft metals when ceramics are involved. Currently, the Ti-Cu-Ti [10], Ti-Ni-Ti [11] and Ti-Cu-Ni [12] interlayer used for diffusion bonding of ceramics to metal has been investigated. Ti is the most attractive active element for almost all the structure ceramics[13]. Y. Min [14] and R. A. Marks [15] have studied the influence of Nb-Cu-Ni and Cu-Nb-Cu interlayer on the joint properties in the ceramic-metal bonding. Soft Nb was a suitable candidate to buffer the residual stress in the ceramic/metal joints attributed to its lower CTE value ($7.2\times10^{-6}$ $K^{-1}$) than those of ceramics (TiC cermet: $7.4\times10^{-6}$ $K^{-1}$) and steel ($12\sim13\times10^{-6}$ $K^{-1}$) [6,16]. As discussed above, an interlayer containing Ti-Nb was required to be capable of accommodating the incompatible chemical and physical properties between TiC cermet and steel in present study. Additionally, element Nb was infinitely soluble in Ti [17], which avoided the formation of detrimental inter-

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metallic compounds (IMCs), such as $Cu_2Ti$, NiTi and $Ni_3Ti$ [10-12], to a certain extent.

In spite of successful diffusion bonding achieved in above cases, it was noted that the diffusion bonding was time consuming, as 45~120 min was generally required to complete the bonding process [10-15]. In these regards, it was of great interest to shorten the bonding time by further optimize the bonding circle, for the purpose of both productive efficiency and cost saving. Auxiliary impulse pressure can offer an advantage in the process of diffusion bonding because the pressure can enhance the speed of the atomic diffusion [18]. The compressive deformation generated by impulse pressure can fill voids and refine titanium grains[19], which produces more grain boundaries to generate additional diffusion pathways. Thus thermodynamically, all of these factors are in good shape to shorten the bonding time, and then accelerate the bonding process. Moreover, a reduction in bonding time, which can retard the excessive growth of interfacial IMCs, would in turn potentially contribute to the bonding strength.

To this end, a modified bonding technique, impulse pressuring diffusion bonding (IPDB) using Ti-Nb interlayer was intended in the current investigation, to realize robust bonding of TiC cermet to steel within a greatly reduced duration.

## 1 Experiment

The base materials, hot pressure sintered (HPS) TiC cermet and commercially 304 stainless steel (SS, 06Cr19Ni10), were processed into 3 mm × 4 mm × 8 mm and 3 mm × 8 mm × 30 mm, respectively. The multilayer metals of pure Ti and Nb, with a thickness of 20 and 30 μm respectively, were used. The chemical composition and room temperature thermophysical properties of substrates and interlayer are given in Tables 1 and 2. The mating surfaces of the specimen were prepared by conventional grinding and polishing techniques, and subsequently cleaned in acetone to eradicate any residual contamination. Bonding trials were performed in a Gleeble-1500D tester and the parameters were: temperature $T$=890℃, pulsed compressive load $P_{min}$= 2 MPa and $P_{max}$= 10 MPa, impulse frequency $f$ = 0.5Hz, bonding time $t$ = 4~12 min, in vacuum maintained at $1\times10^{-3}$Pa. The assembly sequence of samples was TiC-Ti-Nb-SS.

Subsequent to bonding, selected specimens were sectioned and microstructural observations were conducted in field emission scanning electron microscope (FEI-SEM, FEI Nova400) using back scattered mode (BSE) to reveal the interfacial reaction layers. Chemical concentration profile across the joints was determined using energy dispersive spectroscope (EDS). Room temperature shear tests were performed in a testing machine (Instron 1342) at a crosshead speed of 0.025 mm/min to examine the mechanical properties, as displayed in Fig.1. Fracture morphologies were observed by SEM and X-ray diffraction (XRD) to identify the fracture location and characteristic of the joints.

## 2 Results and Discussion

### 2.1 Mechanical properties

Shear strength of the IPDB joints with the change of bonding time and the axial shear load-displacement curve are given in Fig.2. The shear strength is determined by the formula $\sigma = F/S$ ($\sigma$ is the strength, MPa; $F$ is the loading, kN; and $S$ is the bonded acreage of the sample 3 mm × 8 mm). The TiC cermet/SS joint is destroyed at the maximum load and then the load decreases suddenly, shown in Fig.2b. This means that fracture of the TiC cermet-SS joint is a brittle manner.

It is well known that the most important parameters for diffusion bonding, bonding temperature, pressure and holding time, are not independent with each other. At a given temperature, the bonding time required to complete the bonding is a function of the applied pressure. A higher pressure would preferentially result in reduced time required. In the short time range of 4~6 min, the joints exhibit a rather low strength of approximately 20~54.8 MPa. As the bonding time increases, so does the number of impulses ($f$ at 0.5 Hz). When $t$＜10 min, elemental diffusion gradually increases as the number of impulses multiplies. The limited macroscopic deformation of the joint can be attributed to the increasing loading cycle the substrate experienced, which further promotes the atomic diffusivity[19]. It is thus deduced that the poor bonding quality of the joints is precisely because of the insufficient mass transfer of the reaction interface in inadequately bonding time. The

**Table 1 Chemical composition of substrates (wt%)**

| Material | C | Ni | W | Mo | Ti | Cr | Mn | S | P | Fe |
|---|---|---|---|---|---|---|---|---|---|---|
| TiC | 19.6 | 9.54 | 2.94 | 1.40 | Bal. | | | | | |
| SS | 0.12 | 8.43 | | | | 18.67 | 1.35 | 0.03 | 0.035 | Bal. |

**Table 2 Room temperature thermo-physical properties of Ti, Nb and substrates [6, 16]**

| Materials | Melting point/K | Coefficient of thermal expansion/$\times10^{-6}$ K$^{-1}$ | Elasticity modulus/GPa |
|---|---|---|---|
| Ti | 1913~1943 | 9.4 | 115 |
| Nb | 2468 | 7.2 | 105 |
| TiC | 3067 | 7.4 | 410~510 |
| SS | 1399~1455 | 12~13 | 193 |