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Short communication

Joint between $MoSi_2$ and 316L stainless steel surfaces and its interfacial mechanical properties

M. Wang, D.B. Bi, W.G. Qin*

Industrial Group of Shandong University, Shandong University, Jinan 250061, PR China

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ABSTRACT

In this study, we proposed a new method using the spark plasma sintering technique to join ceramics to alloys. $MoSi_2$ and 316L stainless steel were chosen as sample materials and can be welded well with graded interlayers. We found that dense uniformed joints were achieved because of the comparable coefficient of thermal expansion of the interlayers. Furthermore, such a compatibility between the graded interlayers prevented $MoSi_2$ with low toughness from the occurrence of microcracks resulted from the residual stresses formed during cooling of the joint.

1. Introduction

Ceramics such as molybdenum disilicides ($MoSi_2$) are very promising for structural applications at high temperatures because of their high melting point (T_m = 2030 °C), moderate density, excellent oxidation resistance, good electrical conductivity and stability in a variety of corrosive environments [1,2]. There are several potential applications that have been identified for $MoSi_2$ in the aerospace, automotive, energy sources and so on [3,4].

In order for $MoSi_2$ to be used in various industries, it is necessary to join it to other materials, such as ferrous and non-ferrous alloys, since such ceramics are generally brittle. However, direct welding of $MoSi_2$ to most metals and alloys is not possible owing to differences in CTE and the necessity for high joining temperatures, which can lead to joint failure upon cooling because of large residual stresses. To solve this issue, efforts have been made to employ various welding/jointing techniques. For example, Conzone et al. [5] first used active brazing techniques to obtain the tense uniformed joints of $MoSi_2$ to 316L; however, the Cu/Si phase produced at the $MoSi_2$/Nb interface limits the use temperature of $MoSi_2$/316L joints because it has a relatively low melting temperature (852 °C) and the successful use of this joint at temperatures approaching 852 °C could only be achieved in a non-oxidizing environment.

The spark plasma sintering (SPS) technique is a simple and promising method for materials processing. It is considerably practical and may be applicable in various industries to reduce the thermal stresses of joints if suitable technological parameters are adopted. Especially, to better exert the advantage of this technique, it is simple and convenient to design various graded material interlayers in order to improve the compatibility of different materials and to reduce the thermal stresses of each layer. It is worth noting that efforts have been made to apply the SPS technique to joining different materials since the last decade. For example, Fan et al. [6] joined Mo to CoSb3 using SPS by inserting a Ti interlayer, whereas Liu et al. [7] joined dissimilar nanocrystalline materials by a reactive synthesis. In the above studies, generally, the joint with excellent properties was achieved at moderate temperatures. However, the residual thermal stress induced during cooling, a decisive factor in the joining strength in the graded interlayer, can always occur and is hardly effectively and accurately measured by X-RAY and other conventional methods [8–11].

In this work, we developed a new approach of SPS by the use of 9 graded interlayers to join $MoSi_2$ to 316L stainless steel. The joint with excellent properties was achieved at moderate temperatures.

2. Experimental procedure

99.0% $MoSi_2$ (<10 μm), 99.9% ZrO_2 (40 nm), and 98.0% 316L stainless steel (165 μm) powders were purchased from the local commercial company. Table 1 gives the chemical compositions of 316L powders. According to the design of 9 interlayers (Fig. 1), the volume fraction of $MoSi_2$/316L graded interlayers was obtained, as shown in Table 2. Powders of each layer were mixed in agate ball

* Corresponding author.
E-mail address: wgqin2@126.com (W.G. Qin).

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Table 1
Chemical compositions of 316L stainless steel (Wt%).

C	Si	Mn	P	S	Ni	Cr	Mo	Fe
≤0.030	≤1.00	≤2.00	≤0.035	≤0.030	10.35	17.4	2.89	Balance

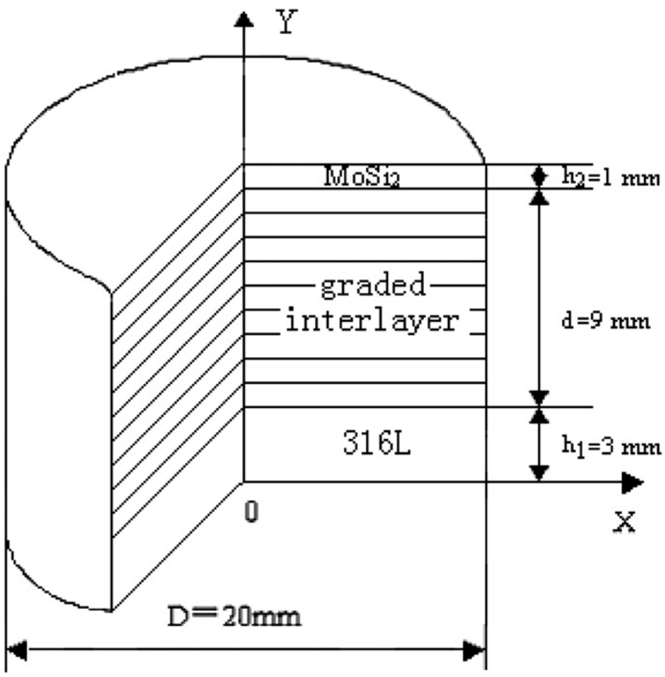

Fig. 1. Distribution and dimension of different gradient interlayers.

Table 2
Volume fraction of $MoSi_2$/316L graded interlayers.

Layer	316L stainless steel powder (%)	$MoSi_2$ powder (%)
A	90.10	9.90
B	76.15	23.85
C	64.11	35.89
D	53.03	46.97
E	42.57	57.43
F	32.56	67.44
G	22.92	77.08
H	13.57	86.43
I	4.47	95.53

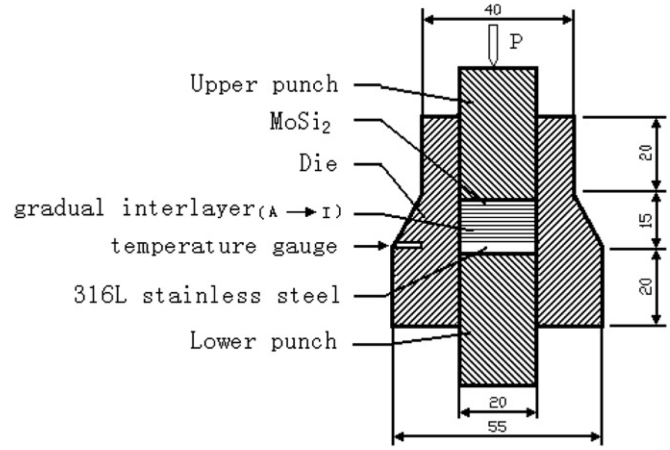

Fig. 2. Schematic illustration of the sintering processing of the graded interlayers.

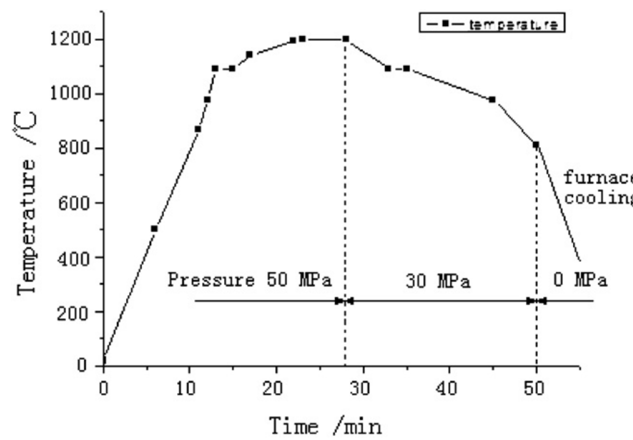

Fig. 3. Variations in temperature with time during a sintering process.

grinding cans in a planetary ball miller (QM-SB type) for 4 h. The resulting powder mixtures were then cold pressed layer by layer in a graphite die (φ20 mm × 55 mm). Perfect chemical bonding can be achieved when a sintering process is completed in the die. The entire powder assembly was sintered in a SPS furnace, as shown in Fig. 2. Fig. 3 illustrates variations in temperature with time during a sintering process.

The specimens after sintering process were characterized using a conventional optical microscope. For microstructural observations, joints were cut off along the cross-section, and then the

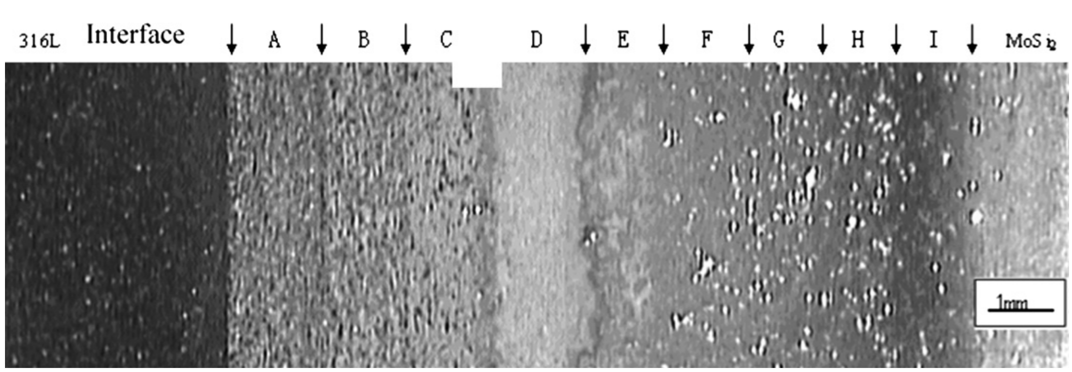

Fig. 4. A typical optical microstructural image of the $MoSi_2$/316L joint.