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Formation of TiC by the application of Ti6Al4V machining chips as flux compounds of tubular wires

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Abstract. Titanium carbonates (TiC) have high hardness and wear resistance, being thus widely present as a phase present in various mechanical components subject to wear mechanisms. Its application on a large industrial scale becomes relatively low, due to the high cost of titanium commercial alloys. On the other hand, large amounts of chips are generated in the manufacture of prostheses and orthodontic implants, where titanium alloys (ASTM F67 and ASTM F136) are widely applied. The attractiveness of these residues lies in the fact that titanium is the major element present in alloys (at least 90% by weight) and are discarded at low cost when compared to commercial alloys. In order to re insert these residues in the production chain, ASTM F136 (Ti6Al4V) alloy chips were subjected to grinding processes to obtain powders with a grain size of less than 40 mesh and used as flux components in tubular type wires MCAW for manufacturing consumables, promoting the formation of TiC in the welding metal. The deposited cords presented low weld discontinuity index with a uniform distribution of TiC particles along the microstructure, resulting in considerable fractions of carbonate areas in the welds and presenting a considerable increase in micro hardness.

1. Introduction

The deposition of hard coatings composed of metallic carbides has been presented with an efficient alternative in resistance to the mechanisms of wear [1,2]. The carbides have a high melting point, are chemically stable and have a high hardness. In welding, chromium has been one of the main elements present in addition metals with the purpose of reacting in the form of carbides (Cr_7C_3), establishing high hardness and resistance to abrasive wear [3-6]. On the other hand, studies show that titanium carbide (TiC) have better mechanical properties and resistance to wear, however, they have a higher commercial value when compared to chromium [3,7].

Due to the biomechanical properties of titanium [8], its alloys have been widely used in the manufacture of orthodontic implants and surgical prostheses which are generally obtained by machining processes, thereby generating large quantities of titanium alloy chips, which in turn are discarded as scraps and low economic value.

ASTM F136-Grade IV (Ti6Al4V) alloy chips were converted into powders by grinding methods and used as components of the metal fluxes used in the formulation of MCAW type tubular wires to form a microstructure composed of titanium carbides with applications aimed at resistance to abrasive wear.

2. Methodology

ASTM F136 - Grade IV (Ti6Al4V) titanium chips were subjected to cleaning processes to remove the machining fluids and subsequently left in the oven for drying. The grinding was carried out in a grinder and classified in sieves with granulometry in the bands of -400+250μm, -250+150μm, -150+50μm and -50μm (Figure 1 and 2). In the present work the fines in the -400+250μm range were used. The fines were subjected to X-ray diffraction tests to identify the present phases.

Chemical composition of the metal flux was determined from the stoichiometric calculations for the formation of TiC, where the mass ratio of chips per mass of carbon (graphite powder) of 10:3 was determined. Tubular wires were fabricated in a forming and drawing machine by forming a SAE 1008 thin strip into a U-shape, filling it with the flux and continuing to roll it into a tubular wire and drawn through dies until the diameter of 2.2mm was reached (Figure 3). Nominal chemical composition of thin strip, fine chips after milling and tubular wire formed are shown in Table 1.

Welding was performed in an Aristo U82 (ESAB) welding machine with the torch coupled in a speed controlled portable car, Figure 4. The welding parameters are presented in Table 2. As base metal a flat bar was used with section of 10x50mm in SAE 1020 low carbon steel.

Figure 1. Apparatus used to grind titanium chips into fine particles.

Figure 2. Aspects of the chip after the process of grinding (left) and classified in a 400μm vibrating screen (right).

Figure 3. Experimental equipment of forming, filling and reduction of tubular wires.

Figure 4. Welding scheme used to deposit the weld cladding on substrate.

Table 1. Chemical composition (wt%) of the thin strip, powders and the tubular wire.

Material	Fe	Ti	Al	V	C
Thin strip	Bal.	-	-	-	0.04
Powders	-	Bal.	4.59	3.02	23.01
Tubular wire	Bal.	12.90	0.86	0.57	4.34

Table 2. MCAW welding parameters.

Welding Voltage (V)	24
Flow rate of argon (l/min)	30
Wire feed speed (m/min)	3
Welding Speed (m/min)	7
Arc Gap (mm)	25
Tubular wire diameter (mm)	2.2

Samples were taken from the weld beads formed as shown in Figure 5. After cutting, the ends were discarded (A 'and B'). Samples with the sections indicated by A and B were embedded in Bakelite and sent to macrographic analyzes (cord geometry), microhardness tests and microstructural characterization. The central samples, C, were prepared in the longitudinal direction of the bead and sent to X-ray diffraction (XRD) analyzes.

Metallographic preparation was made from conventional sanding and polishing techniques. The attack was performed in 2% NITAL solution.

Microstructural characterization was performed in an optical microscope where the generated images were processed in the ImageJ to study the particle size and fraction in the area of the formed carbides. To measure the microhardness, a Shimadzu micro durometer with indentation in the Vickers HV0.3 scale will be used. The determination of the microhardness was made from a line orientation with three indentation rows, starting from the top of the strand until it reaches the base metal and beyond the ZTA, spaced 0.3mm between each measurement, Figure 6.

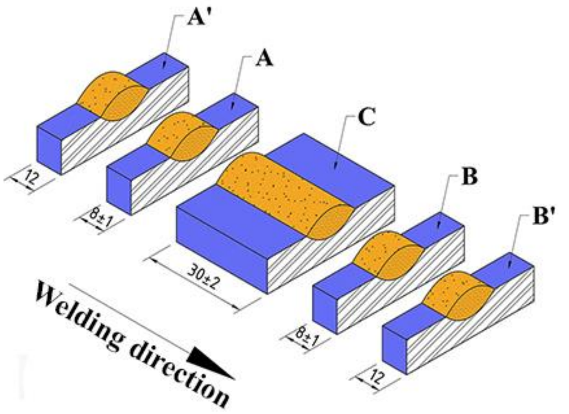

Figure 5. Schematic representation of the specimen sections.

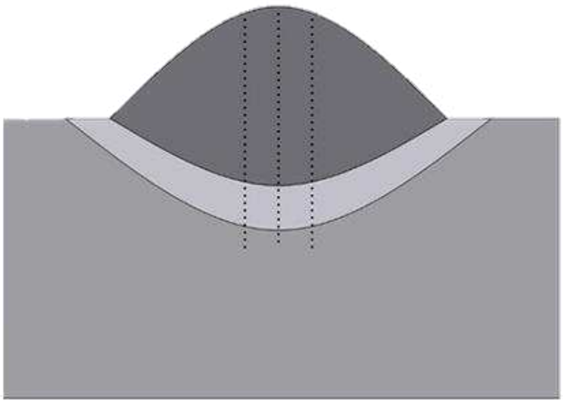

Figure 6. Schematic representation of the microhardness measurements (steps by 0.3mm in each row).

3. Results and discussion

The grinding made from the use of a milling apparatus allowed the formation of fines with a grain size less than 50µm. The XRD analyzes performed on samples of the fines did not identify the formation of titanium oxides, Figure 7. Comparisons by XRD analyzes made on a titanium bar and on the generated fines indicated that the phases present in the fines are identical to those present in the titanium bar.

Wires presented satisfactory aspects as to the form and the efficiency of filling of the flow, [9]. The wire presented an external diameter of 2.252±0.004mm and a thickness of 0.473±0.005mm, resulting in an internal diameter of approximately 1.26mm, Figure 8. The wire filling efficiency presented an average of 10%, Figure 9. Although it is reported in the literature that tubular wires facing the hard coating application show efficiency in the range of 30-50% [10], the addition metals used in the present work have in the flux components with low density and considering the internal space of the wire formed, the maximum possible efficiency will be close to 18%.

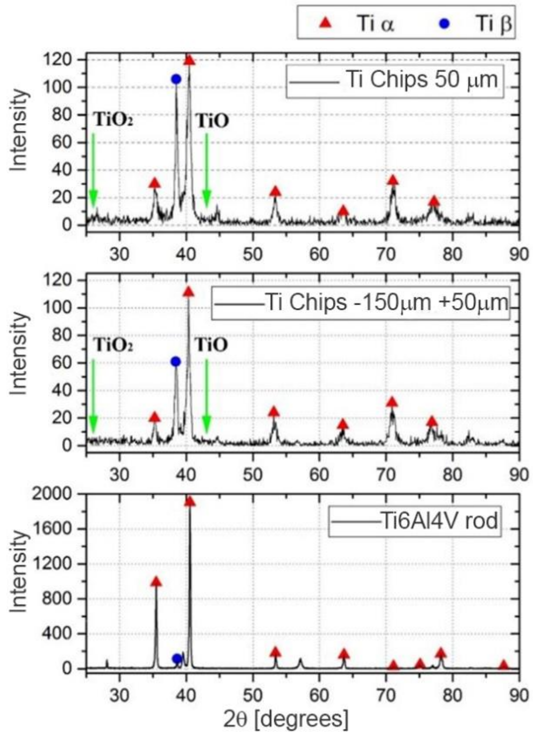

Figure 7. X-ray diffraction of the titanium chips confronted with a Ti6Al4V specimen.

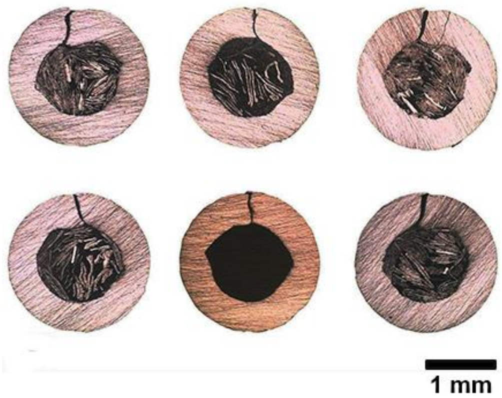

Figure 8. Schematic representation of the specimen sections.

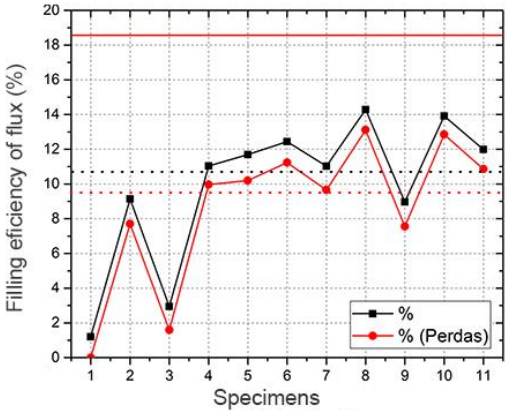

Figure 9. Schematic representation of the microhardness measurements (steps by 0.3mm in each row).

The deposited cords presented a good finish to the presence of spatter indicating that the transfer method may have been short-circuited, Figure 10. In the section samples it is noted that the cords were absent from discontinuities such as pores and cracks, Figure 11 and 12, The mean dilution rate of 50.5±12.29% was higher than those recommended in the literature, where studies indicate that for the application of hard coatings the dilution should be between 10% and 20% [11,12].

In addition to the high dilution rate, the flux share in the weld is highly influenced by the thickness of the metal strip (responsible for the conformation of the wire) that affects the amount of flux deposited per unit length. TiC are characterized by a microstructure consisting of dendritic branches with a rounded or starred morphology [13,14]. However, for welds formed with one pass, it can be seen from the micrographs, Figure 13, that the carbides have a prismatic shape and can thus present a high concentration of stresses at the interface with the matrix, reducing the properties of the wear resistance microstructure [15].

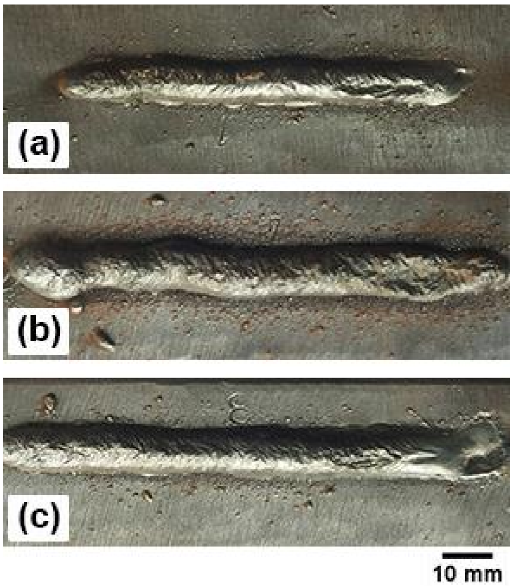

Figure 10. Macrography of longitudinal direction of the melted tracks.

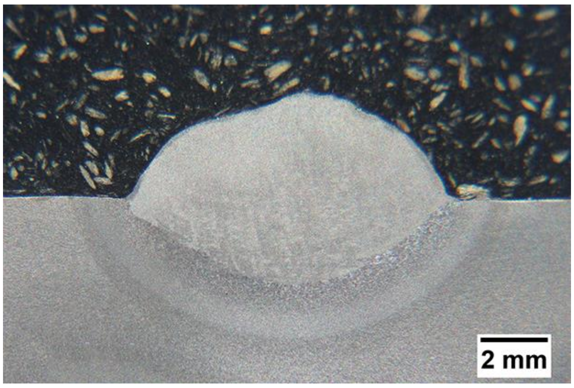

Figure 11. Macrography of transverse cross-section–Specimen 8A.

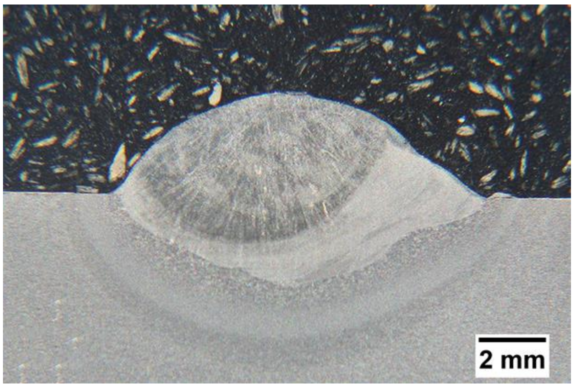

Figure 12. Macrography of transverse cross-section–Specimen 8B.

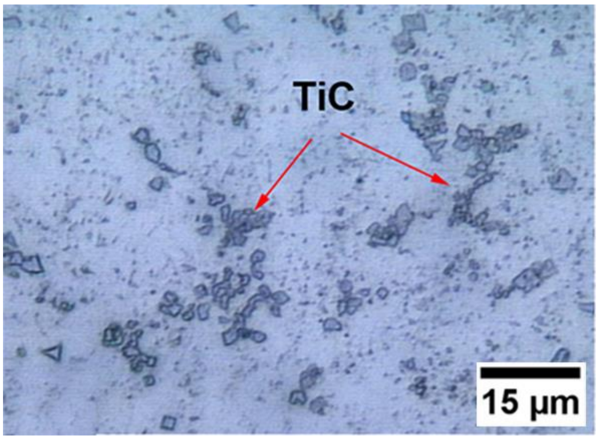

Figure 13. Micrography showing the presence of TiC as a second phase into ferrite matrix.

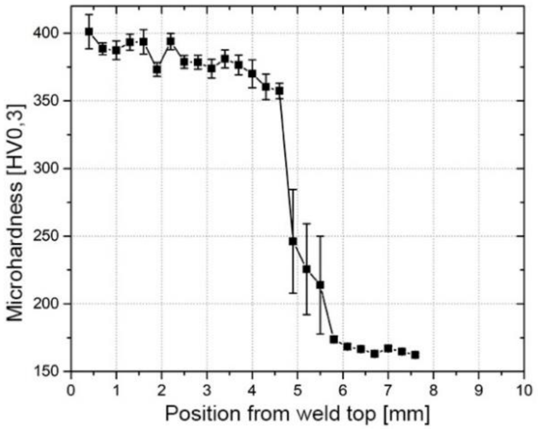

Figure 14. Microhardness profile along the cross-section of weld.

The formation of titanium carbides was well distributed throughout the ferritic matrix, although it presented higher proportions of fine particles (0.75µm to 3.2µm), promoted a volumetric fraction with variations between 11% a 13%, Figure 13. The formation of the TiC may also be evidenced by the considerable increase in surface hardness in the region of the weld, Figure 14, thus hoping that a considerable improvement in the wear resistance will be attributed to the surface. The low dispersion presented by the microhardness values can also be taken with an indication of a microstructure with the presence of very homogeneous TiC. The high hardness of a surface does not mean resistance to wear; however, this is considered as a strong indication in the behavior of the materials when subjected to the wear mechanisms [1].

4. Conclusions

Formation of TiC was evidenced from the use of titanium chips as the flux of the tubular wires. As a result of the presence of TiC the weld showed considerable elevation of surface hardness. The thickness of the metal strip affected the dilution rate in the welds as a consequence of the high iron supply in the weld. The use of metal strips with smaller thicknesses may favor the presence of TiC in the solder and thereby increase the hardness and possibly improve the abrasive wear resistance properties. Titanium carbides presented a prismatic morphology probably as a consequence of the low supply of the titanium in the weld still as effects of the thickness of the tape.

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