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Formation of TiC Ceramic Coating on AISI D2 Tool Steel through Mechanical Milling Technique

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Abstract: *In the present research, the TiC powder was used to coat the surface of AISI D2 substrate by means of mechanical alloying technique. During this novel method, a mixture of titanium and graphite with the composition of Ti-50%mole C, ball-to-powder mass ratio of 30:1 and rotational speed of 300 rpm under pure argon atmosphere in planetary ball-mill were used. Phase transformation, structure of the coating and local composition at different steps was analyzed by X-ray diffraction (XRD), scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy, respectively. It was found that, a dense coating layer with no microcracks and porosity can be fabricated after 35 h mechanical alloying.*

Keywords: *TiC coating, Mechanical alloying technique, XRD, SEM.*

1. Introduction

Tool steels due to their unique properties are widely used in different application such as: cutting and wear tools; nevertheless, their poor wear and oxidation resistance specially in harsh environment become a noticeable limitation for their widespread application[1].

Several methods such as alloying, heat treatment and so on have been applied to improve mechanical properties of tool steels. Among these surface engineering can be an excellent technique to put down their restriction. A variety of coating process, including physical vapor deposition (PVD), chemical vapor deposition (CVD), cold spray, plasma spray, laser cladding and cement-packing have been made to prepare an thick coating layer on substrate surface[2-6]. However, some of the main demerits of these conventional methods, are their high operating temperature, wide limitation in controlling the processing parameters, using high vacuum conditions and expensive sophisticated equipment[7]. Recently, mechanical milling has attracted great deal of attention to synthesize a variety of non-equilibrium and equilibrium intermetallic and ceramic compounds at room-temperature and ambient atmosphere during a short period of time [8,9].

Different material have been applied and investigated to coat steel surface. Titanium carbides (TiC) can be a workable candidate for coating tool steels. TiC is a promising ceramic which has desirable properties such as showing a specific strength at a high temperature, good stability at oxidation and corrosion environment and high melting point[10-12]. Consequently, it can be considered as a primary choices to improve the properties of tool steel surface.

Coating the metal surface by means of mechanical alloying process has been used by different scholars. Pouriamanesh et al. [13] investigated Ni-Al intermetallic coatings on Al plates by means of mechanical alloying method. Mohammadnezhad et al. [14] illustrated that this novel method could be used to prepared NiAl coating on carbon steel substrate. In addition Romankov et al. [15-18] successfully applied this process for depositing different coating such as Ti-Al, TiN and TiC/TiN on different materials.

2. Experimental procedures

In this experiment, AISI D2 cold-work tool steel plates with dimensions of 5×10×30 mm were used as a substrate material. Table 1 illustrates the chemical composition of the used steel. Ti (99.99%, <40 µm) and Graphite (99%, <30 µm) with a composition of Ti-50% mole C was used in the deposition of the coating as a starting material. A planetary ball-mill with hardened steel vial (160 ml in volume) under pure argon atmosphere at rotational speed of 300 rpm and ball-to-powder mass ratio 0f 30:1and balls (10,12 and 14 mm in diameter) were carried out. The duration of MA was between 13 and 50 h.

The phase evolution of un-milled and the coating were identified by X-ray diffraction (Phillips X'Pert) using Cu Kα radiation (λ= 0.1542 nm) with a step size 0.05˚. Scanning electron microscopy (SEM) and an energy-dispersive X-ray analyzer (EDS) were used to observe the microstructure of the coatings.

Table1: Chemical composition of the D2 steel used as the substrate material.

Chemical element	C	Cr	V	Mo	Mn	Si	P	S	Fe
Weight percent	1.54	12.5	0.95	0.70	0.30	0.25	0.02	0.015	Bal.

3. Results and Discussion

Fig. 1 shows the XRD patterns of un-milled powders and as-milled sample through mechanical milling after different milling time. it can be seen that until 10 h milling there is no peaks from Tic. On further milling up to 10 h, some TiC peaks abruptly replaced with Ti peaks. And finally after 20 h milling it obvious that all starting powders changed to TiC. With increasing in mechanical alloying duration more than 20 h, indicating that no new compounds were produced and only TiC peaks were broadened which can follow from decreasing in crystalline size and noticeable increase in internal strain due to the repeated ball impacts.

Fig. 2 illustrates cross-sectional SEM images of the coated surfaces at different milling time. During ball-milling, the top layer of substrate was subjected to high- energy ball collisions. As a result of transferred energy at the collision moment, powder particles which were placed between substrate surface and balls attached to substrate in some regions. In addition, these high-energy impacts increased lattice defects and lattice strain which originate a large number of microcracks and fractures in the surface. Fig. 2 a demonstrates microcracks and sporadic coatings which were fabricated after 13 h of mechanical alloying. As it was explained above the TiC compounds could be formed as a conclusion of the synthesis reaction between Ti and C after specified period of mechanical alloying. With increase milling, powder particles moved into the mocrocracks and pores of the steel substrate; also, the fracture particles of steel substrate can be mixed mechanically with powders and adhered to the substrate again; therefore, mixing between coating materials and substrate starts; consequently, a composite coating layer formed after 20 h milling. This can be seen in Fig. 2b and c.

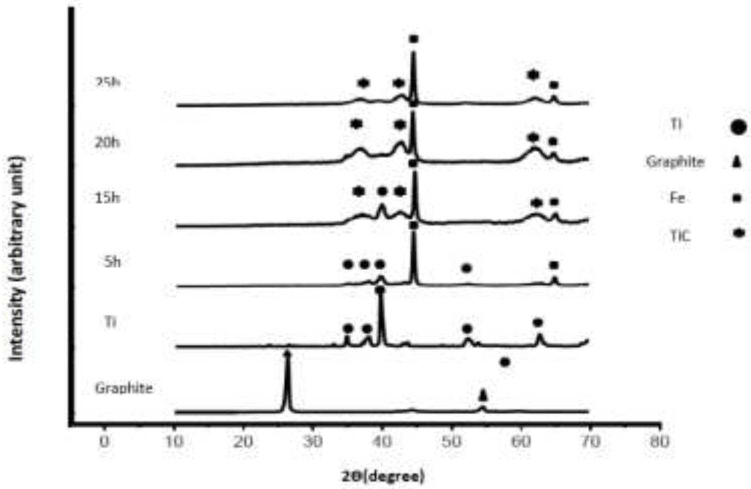

Fig. 1: XRD pattern of un-milled and ball-milled substrate at different time.

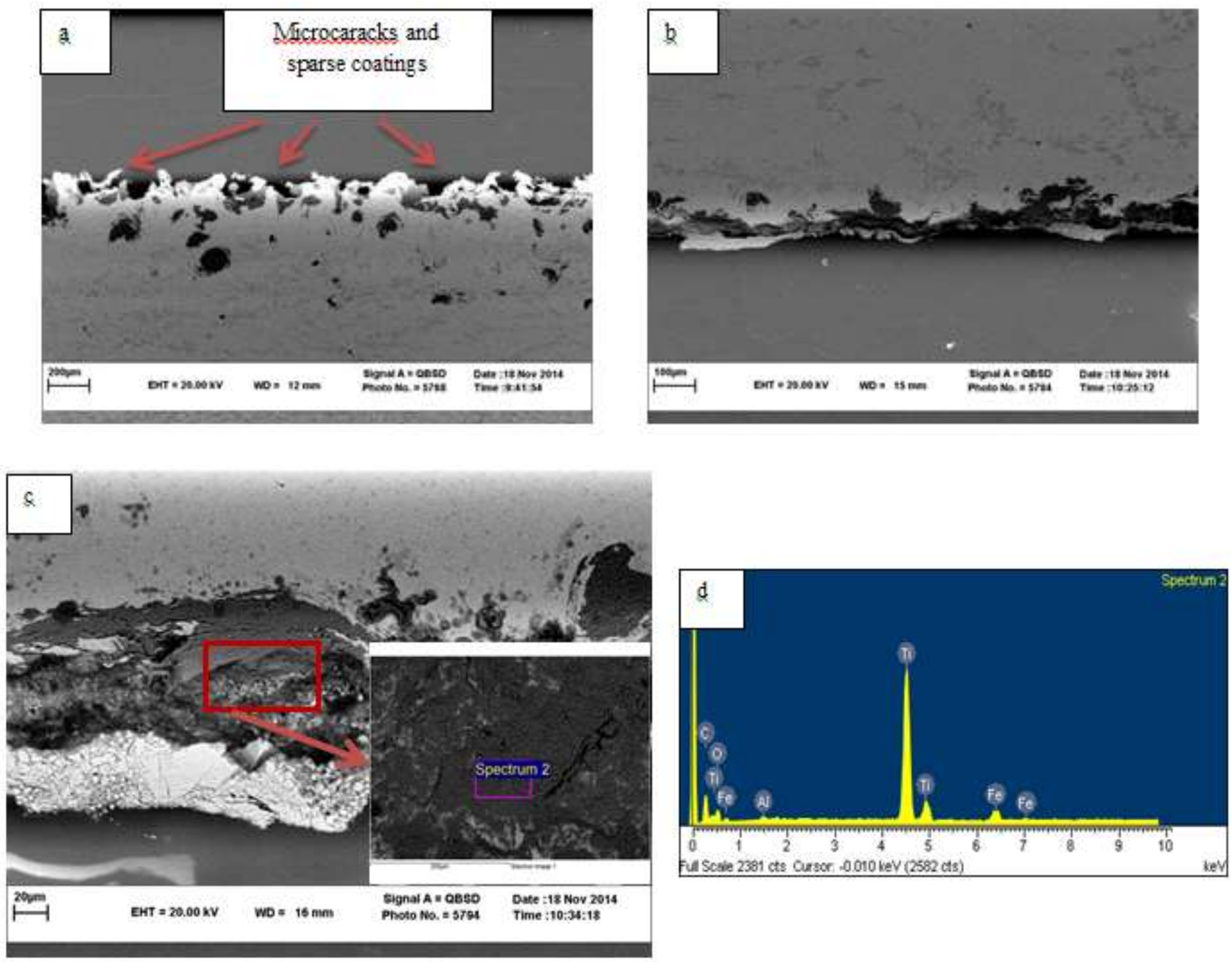

Fig. 2: SEM image and EDS analyze of the cross section of MA-Coatings after (a) 13h, (b,c) 20 h, (d) EDS of (c)

Prolonged milling increased ball impacts; therefore, the amount of coating particles were cold-welded into the surface grew up dramatically. As a result after 35 h milling a dense coating with high apparent density, free of microcracks and porosity and good adherence to substrate formed on the substrate surface (Fig. 3a). Fig. 3c shows the coating structure and its interface with substrate. More increase in milling time result in fracturing of the coating layer due to the development of cracks (Fig. 4a and b).

It is assumed that formation mechanism of deposited TiC coatings by MA includes 3 different stages. First, in the initial stages of mechanical milling the powder particles were soft and had high tendency to adhere and weld. In addition ball collisions implies high amounts of plastic deformation on the surface layer. Consequently, the substrate surface became activated. On the other hand, chemical reaction between starting material and cold welding turns into the superior phenomenon. Second, during the course of mechanical milling, at the middle stages, an obvious equivalence is created between cold-welding and fracturing. In this condition, coating thickness remains steady. Lastly, with increasing milling time, the strain increase sharply so the top layer of the coating become work hardened and began to fracture and peel. As a result at the final stages fracturing is more dominant.

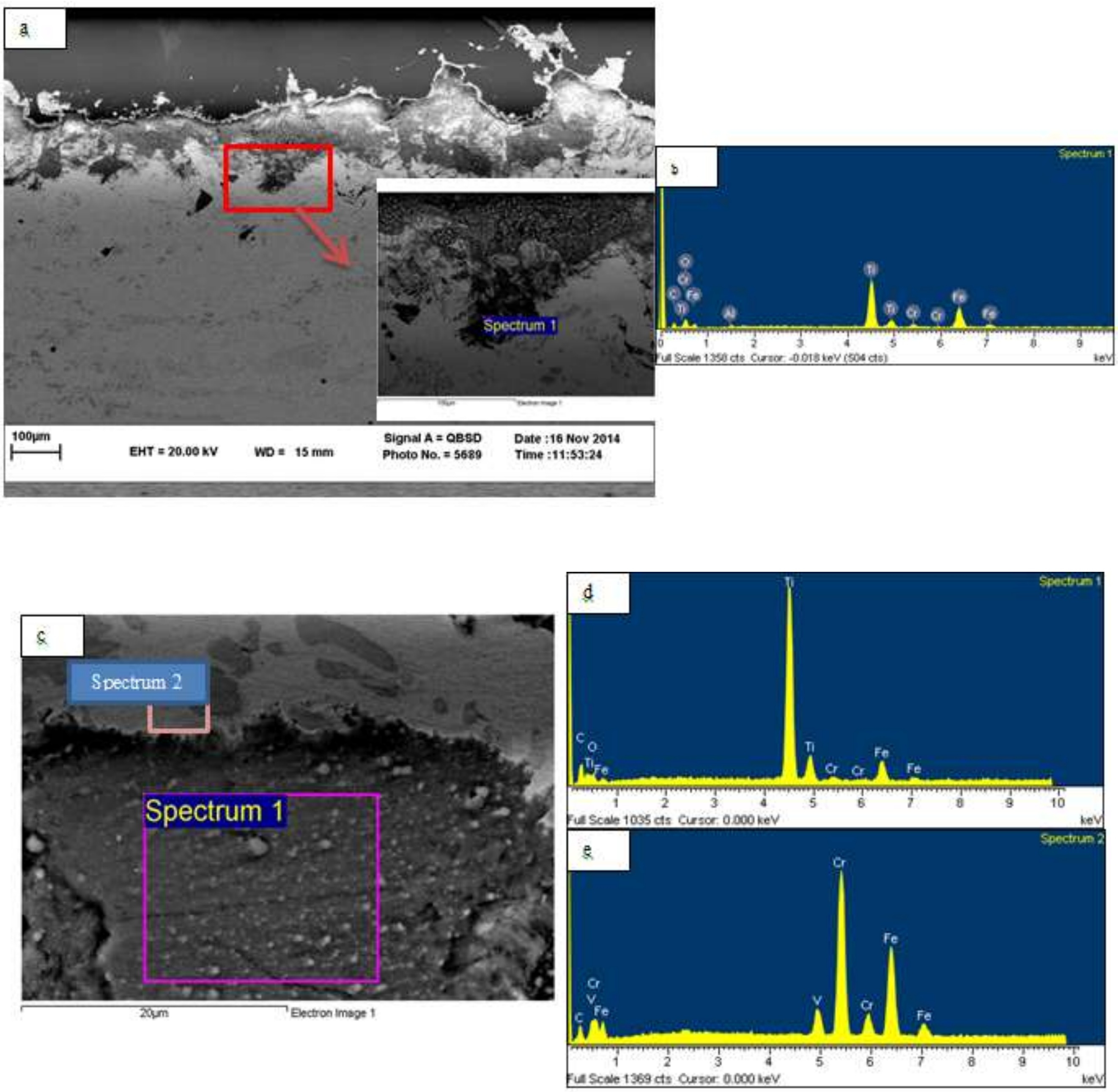

Fig. 3: SEM image of cross-section of MA-coating after 35h milling. (a) 200X, (b) EDS of (a), (c) 5000X, (d,e) EDS of (c).

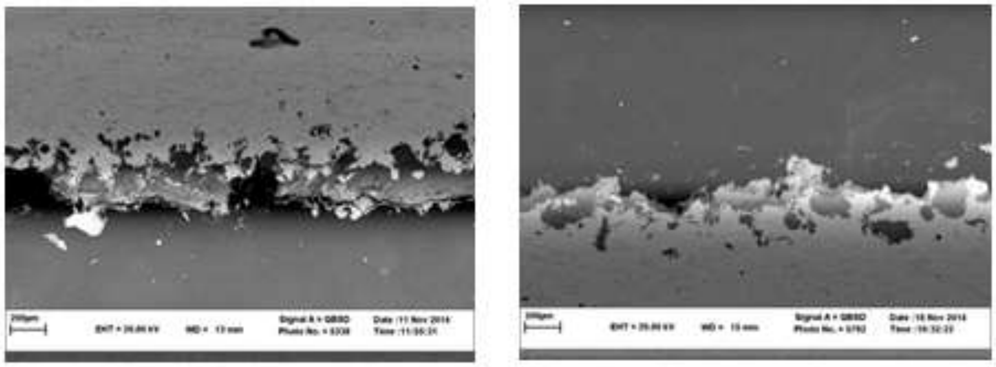

Fig. 4: SEM micrographs of the cross-section of MA-coating after 50 h milling.

4. Conclusion

Formation of TiC coating on AISI D2 cold-work steel substrate is possible through mechanical alloying technique. The TiC compounds were produced during this method under reaction of Ti and graphite powders due to the high energy ball impacts. It was obvious that cold-welding and fracturing are two competitive phenomenon during this process. SEM images and EDS analysis indicate a mix layer of coating material and substrate elements under detachment of fragmental particle and diffusion of powders into microcracks.

5. References

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