Cladding of stellite composite on carbon steel by gas tungsten arc welding (GTAW)

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Abstract
This paper deals with the investigation of the microstructure and hardness of steel samples cladded with satellite 6-WC composites by using gas tungsten arc welding (GTAW) process. For this purpose, steel samples were coated with unreinforced and reinforced stellite (by 20, 30 and 40 wt.% WC). The cladded samples were evaluated by metallographic studies, microhardness measurement and X-ray diffraction analysis. In order to reduce dilution and to increase the hardness, samples were coated by two layers of similar chemical composition. The results indicated that in samples cladded by reinforced stellite, with an increase in tungsten carbide content, the amount of hypoeutectic phase (γ + (γ + WC)) increased. This is accompanied by an increase in hardness.

Keywords: Cladding, satellite, composites, GTAW

1. Introduction
Stellite 6 is a type of wear, corrosion and oxidation resistant Co-based superalloy which is used for cladding. This alloy is widely used in oil and gas industry and power plants since it maintains hardness up to 500°C, wear resistance and mechanical and chemical segregation resistance in a wide range of temperatures[1)]. In this regard, satellite 6 is used in manufacturing of pump shafts, bearings, contact surfaces in industrial valves, combustion engine valves and hot working molds.

It has been reported in the literature that microstructure of satellite 6 clads consists of cobalt-rich and carbide phases with hardness of about 395-400 VHN. The addition of reinforcement can increase hardness and wear resistance of stellite[2)].

In this study, the effect of reinforcement on microstructure and hardness of stellite were investigated. Tungsten carbide with hardness of 2242 VHN was used as reinforcement in order to increase hardness of stellite coatings[3)]. The amount of WC was selected according to WC-Co binary phase diagram (Fig. 1) to achieve cobalt-rich and hypoeutectic phases in the microstructure of coatings.

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2. Experimental procedure
In this study, plain carbon steel (DIN1.0570 or St52) disc samples (55 mm dia) were used as the substrate. The chemical composition of the substrate material is shown in Table 1. Stellite and tungsten carbide powders were used as coating materials with average particle sizes of 30 and 25μm, respectively. The chemical composition of stellite 6 is given in Table 2. Scanning electron micrographs of stellite and tungsten carbide powders are shown in Figure 2.

Before GTAW process, the samples were grown and then cleaned with acetone. For better distribution and uniformity of tungsten carbide in stellite matrix, powders of tungsten carbide and satellite were ball milled for 1h in a planetary mill under protective argon atmosphere. Then, the milled samples were uniaxially cold-pressed in a 55 mm diameter cylindrical die to produce composite discs for cladding.To prevent solidification and hot cracking (due to different thermal expansion coefficients of reinforcement and matrix materials), the substrate and coating material were pre-heated at 250 °C for 20 minutes. Then, TIG surfacing process was performed and subsequently, post-process heat treatment was applied.

To prepare samples for metallographic studies and microhardness measurements, a layer with a thickness of 0.3 mm was removed from the surface of cladded samples. Then, samples were etched in aqua solution ($3HF:1HNO_3$). The phase composition and microstructure of the cladded samples were examined by X-ray diffraction and optical microscopy.

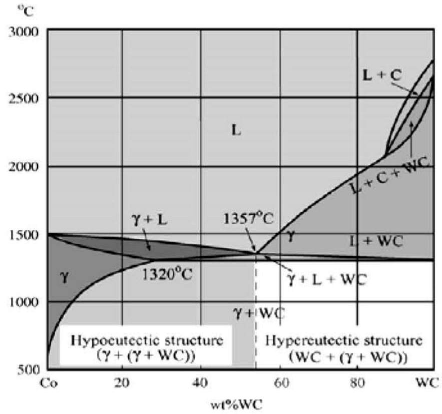
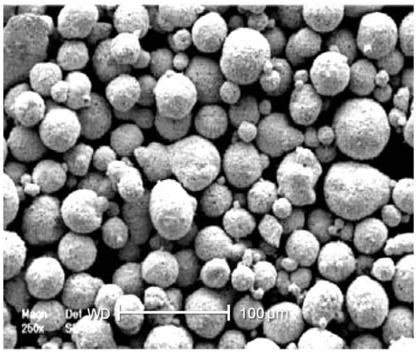
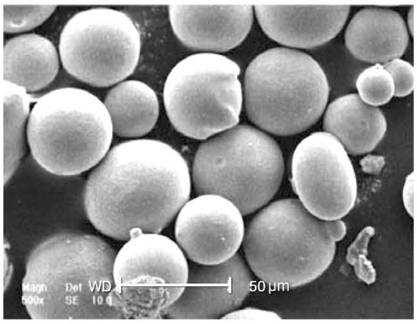


Fig.1. Binary WC-Co phase diagram.



(a)

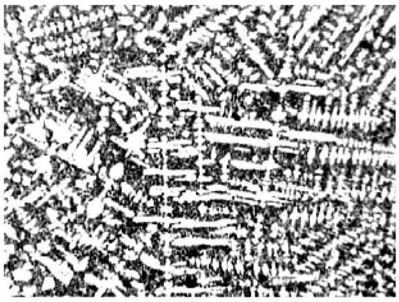


(b)

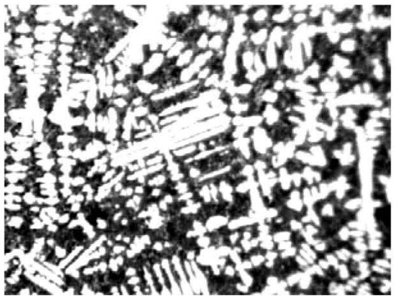
Fig.2. SEM micrograph of cladding materials (a) Se7etellite 6 (b) tungsten carbide .

3. Result and discussion

Optical micrographs of typical cladded samples are shown in Figure 3. The microstructures consist of bright and dark areas. The bright regions represent cobalt-rich (gamma) phase and dark regions show interdendritic eutectic phases. The microstructural shift from cellular to dendritic can be observed with variation in temperature gradient due to change in constitutional supercooling [4].

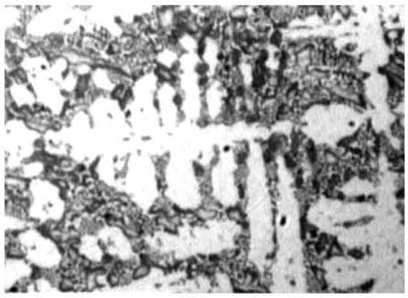


(a)



(b)

(c)



(d)

Fig.3. Optical micrographs of (a) clad layers made with powder mixture of stellite+40%WC (b) stellite+10%WC (c) and (d) lauve phases and interdenderitic eutectics.

Table 1. Chemical composition of substrate (wt%).

C	Si	P	S	Mn	Ni	Cr	Mo	Fe
0.305	0.497	0.0114	0.0222	1.49	0.0907	0.0458	0.0372	Bal

Table 2. Chemical composition of satellite 6[2] (wt%).

C	Cr	Si	W	Fe	Mn	Mo	Ni	Co
1.3	28.6	1.1	4.9	1.9	0.3	<0.1	2.2	Bal

During solidification of weld metal, dendrite growth direction is perpendicular to the fusion line because temperature gradient is maximum in this direction. However, dendrites tend to grow in simple growth directions, i.e <100> for metals with FCC crystal structure. Here, a competitive growth occurs and dendrites with misorientation to that direction will disappear. In Figure 4, a microstructure with competitive growth can be observed. Structure at the boundary of two cladding layers has slightly coarsened due to remelting and resolidification of the first layer while the second layer was cladded [5].
The hardfacing material shrinks when it is cooled to room temperature. This can be a source of residual stress in the coated samples. When the thermal expansion coefficient of base metal is lower than that of the coating material, residual stress is more than when expansion coefficients are equal[4, 6]. Effects of pre- and post-process heat treatment were also evaluated. The results showed that transverse and longitudinal cracks were present in the cladded samples without application of pre heat treatment [7].

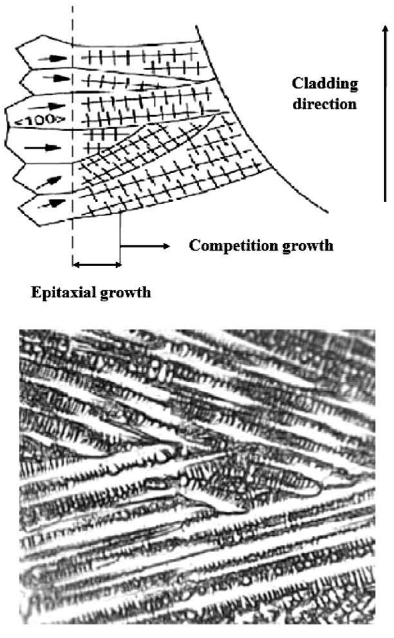


Fig.4. The effect of thermal gradient on competitive growth of dendrites.

XRD patterns (Fig. 5) confirmed the presence of various carbides such as CoC_x, WC and Co_3W_3C in the samples coated by satellite 6-WC composites. It should be mentioned that these phases were not observed in the samples coated with unreiforced stellite.

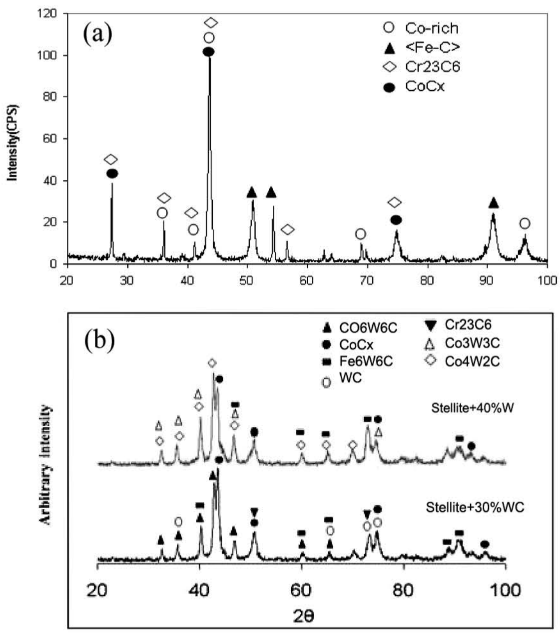


Fig.5. X-ray diffraction pattern of (a) Stellite 6 (b) Stellite with 30%,40% WC.

According to WC-Co binary phase diagram (Fig.1), a eutectic transformation occurs in 55% WC composition at 1357 °C. So, in samples with WC less than 55 wt%, a hypoeutectic ($\gamma + (\gamma + WC)$) structure was observed. The structures observed in stellite-WC composite coatings (Fig. 3) were in accordance with the WC-Co binary phase diagram.
The hardness profiles of cladded samples can be seen in Fig. 6. The hardness of surface layers is less than that of subsurface layers due to the presence of oxides and surface defects. A sharp hardness decrease was observed at approximately half of the thickness of cladded layer toward fusion line arising by growth of the microstructure due to low temperature gradient. Microhardness measurements also showed that the coating produced from unreinfroced satellite 6 has a hardness of about 390-400VHN. The addition of reinforcement has increased the hardness. In this regard, the hardness of coated samples containing 20, 30 and 40 wt.% WC, is in the range of 455-450, 500-520 and 540-560 VHN, respectively [4,7].

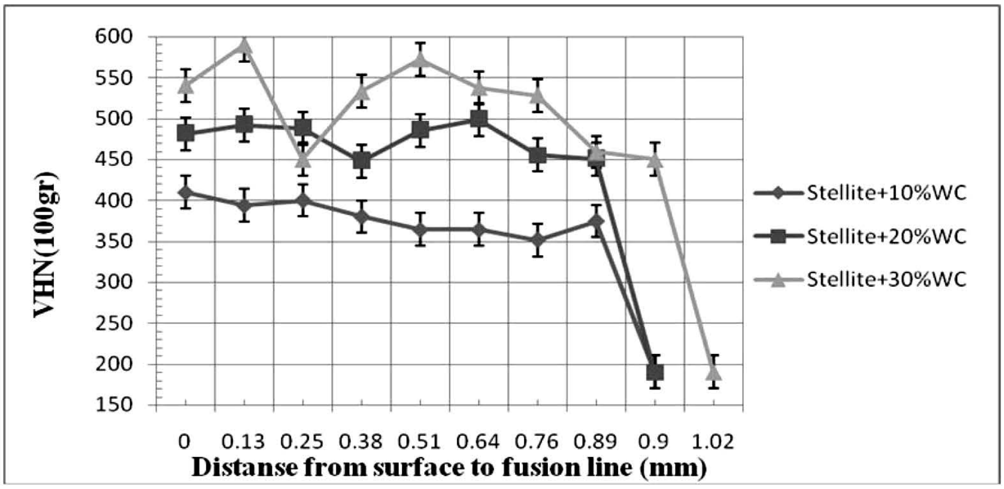


Fig.6. Hardness profile of clad layers with different content of reinforcement.

4. Conclusions

● Cellular and dendritic microstructures with interdendritic eutectic phases containing cobalt-rich regions (Lauve phases) and M_7C_3 and $M_{23}C_6$ carbides were observed in all samples cladded with satellite 6-WC composites.

● With an increase in tungsten carbide content, the hypoeutectic phases (γ + (γ + WC)) and hardness of the samples were increased.

● Use of pre and post heat treatment was effective in decreasing the contraction and prevention of solidification and hot cracking.

● Use of two layers in cladding increased surface hardness due to reduction in dilution.

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