Morphology and Performance of 5Cr5MoV Casting Die Steel in the Process of Surfacing

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Abstract. To investigate the microstructures and mechanical properties of the deposited metal on surface of die steel, two layer of weld-seam were prepared on the surface of 5Cr5MoV die steel by arc surfacing. The surface microstructures and microhardness were characterized by scanning electron microscopy, energy dispersive spectrometer and Vickers microhardness tester， respectively. The effect of load on the abrasion resistance and wear mechanism of the base metal and surfacing metal was studied by pin–on-disk tribometer. The results showed that martensite and retained austenite exist in weld-seam，both of them grow up in the form of dendrites and equiaxed grains and microhardness reach 774.2HV. The microstructures of the quenching zone mainly consist of martensite and retained austenite, while tempered martensite is the dominant phase in partial quenching zone. The abrasion resistance of the surfacing metal is superior to the base metal based on the results of wear test. The wear rates of surfacing metal and base metal raise with the increase of load. The wear rates of base metal raise extremely when the load reach 210N. Both of two kinds of materials have the similar wear mechanism, namely, abrasive wear at low load, oxidative wear and adhesive wear at high load.

1. Introduction

Mold is the cornerstone of modern industrial production, the level of mold technology has become an important indicator of the level of industry of a country in the 21st century [1]. Using the mould to process the covering parts of automobile can effectively improve the production efficiency and save the production cost. A set of mould is extremely expensive to manufacture, most studies have found that the failure of cold mould is attributed to mainly continuous load impact, metal wear and the alternation of cold and heat during service resulting in cracking and collapsing [2,3]. Although the new mold materials and the heat treatment technical have been developing continuously, the new mold manufacturing cost is high and the manufacturing cycle is long, therefore the mold repair is a necessary method for prolonging life-span of the mould [4,5].

The purpose of surfacing welding is to restore the size of the mold and improve its surface wear resistance and corrosion resistance, almost all welding methods can be used for welding repair of damaged parts. Welding electrode arc welding and gas shielded welding is widely used for repairing mould. With the continuous development of advanced manufacturing technology, the original repair can become an improved repair that can exceed the original performance [6]. According to statistics [7], the average efficiency of welding repair measures is ten times more than that of the original measures, and the efficiency of surface engineering measures can even be more than 20 times. Electrode arc welding repair with simple equipment, easy operation, strong applicability, is especially suitable for repairing the complicated shape and irregular parts. However, the wear-resisting behavior of new alloy tool steel and the surface after surfacing in different working conditions remains unclear [8]. In this paper, an arc surfacing method was used to simulate the surface repair of a new casting mould steel, the microstructure, microhardness and the wear performance of the welding points under different loads were studied systematically.

2. Experiment

The test material 5Cr5MoV is used for stamping die, the substrate used in this work was a 100mm x100mmx15mm plate, a kind of low hydrogen alkaline surfacing electrode with a diameter of 3.2mm was used. The chemical compositions are shown in table 1. The content of Si, Mn and Mo in the metal is slightly higher than that in the base metal, and the content of C is slightly decreased. The surface hardness of the surfacing surface is enhanced by increasing the content of other alloy elements although the content of C decreased.

Table 1 Composition of base metal and welding metal （*wt.*%）

Element	C	Si	Mn	Cr	Mo	V	Fe
Base metal	0.60	0.35	0.80	4.50	0.50	0.25	Bal.
Welding metal	0.56	1.26	1.67	4.06	1.84	-	Bal.

According to the actual production of mold company, the sample were treated at 1133K for 5h annealing treatment before welding. The model were surface hardening treated by MICO-L 50MF high frequency induction heating test machine which actual power was 35kw, heating 300s and air cooling. The final surface hardness reached 58HRC and the depth of the hardened layer reached 5mm. The welding process parameters were as follows: welding speed 40mm/min, welding current 110–130A and welding voltage 25V. Interpass temperature was controlled at 353K, the macrohardness of the surface was 59-62HRC after welding.

The wear resistance of hardfacing alloy was measured by MG-2000 high speed friction wear test machine. The size of friction pin was φ6mm×12mm. The samples of base metal and surfacing were tested under the load of 120N, 150N, 180N and 210N respectively. The sliding speed was 320 r/min (1m/s), and the abrasive disc was GCr15 steel. Wear rate W in the following formula was used as the evaluation standard of wear resistance:

$$W = \Delta m / L$$

W is the wear rate, Δ m is quality differentiation, L is the total stroke of wear process (600m). The microstructure and wear morphology and EDS analysis were observed by Zeiss optical microscope and scanning electron microscope (EVO18). The microhardness of the welding joints was analyzed by microhardness tester.

3. Results and discussion

3.1. *microstructure analysis*

Figure. 1 shows the microstructure of the matrix after surface high frequency induction quenching. It is easy to find that the microstructure is fine needle martensite mostly, while a small amount of martensite is thicker. It is due to the heating rate is very fast, which results in high quenching temperature and fast speed of cold, so it can get refinement martensite after quenching. This kind of fine needle martensite contained the residual stress formed on the surface after quenching, and its hardness is about 3 HRC higher than that of normal quenching [9,10].

Figure.2 shows the microstructure of the surfacing from the HAZ to the welding pool, it can be seen that there are obvious microstructure changes along the depth of welding pool: welding pool, fusion zone, quenching zone, partial quenching zone. The structure and morphology of the deposited metal and matrix were changed significantly along the fusion line.

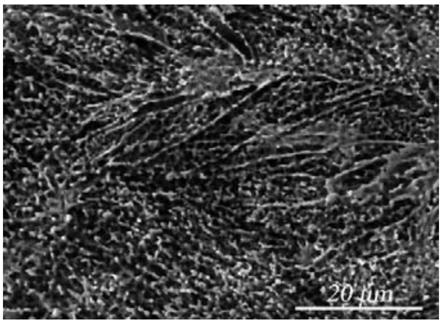


Figure.1 SEM morphology of base metal after high-frequency induction quenching

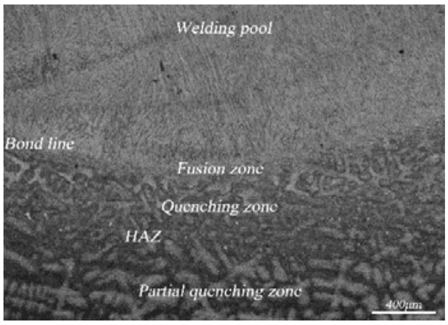


Figure.2 Micrograph of the welding joints of surfacing

Because of the thermal cycling in the base metal, the recrystallization occurred to the structure of the base metal. It is obvious to find that HAZ was separated from quenching zone and partial quenching zone. Most of the microstructure of the partial quenching zone is tempered martensite while quenching zone consist of martensite and small amount of retained austenite.

It is clearly to find the martensite plate in Figure.3, and the austenite that doesn't transform into martensite is remained near the grain boundary. At the same time, a small amount of second phase particles are observed around the grain boundary, the content of Cr, Mo and Si is higher than that of matrix metal according to EDS, while the content of C reached 8.64%. It can be determined that the particles are alloy compound formed by C and other alloy elements. It is due to the thermal cycle of welding, C and other alloy elements have no time to distribute evenly in the process of rapid cooling, which result in element segregate in the grain boundary and forming alloy compound.

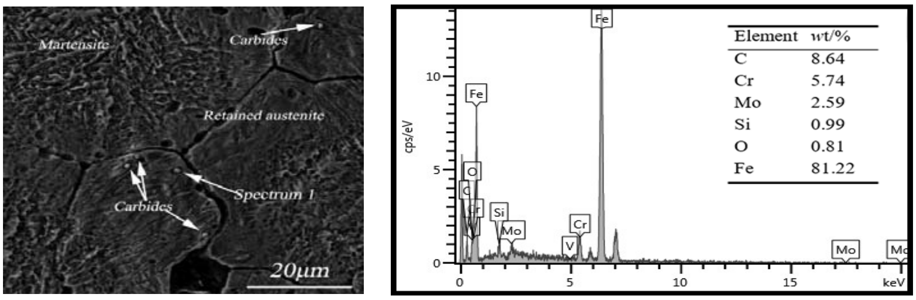


Figure.3 Microstructure of HAZ and EDS analysis of granular particles

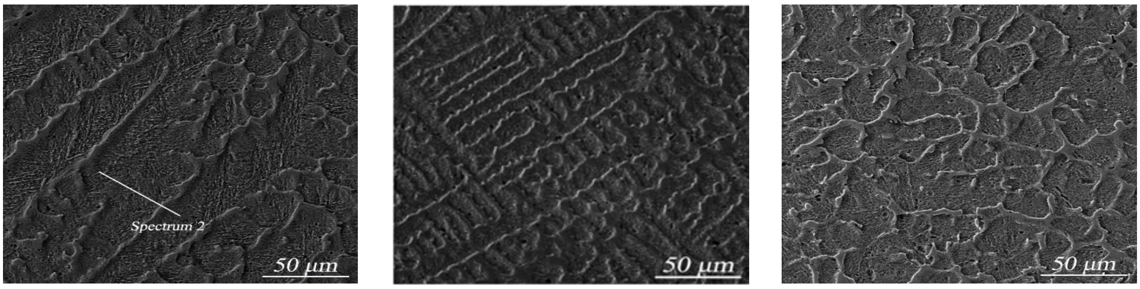
With the distance changing from the fusion line, the microstructure of the surfacing layer obviously changed in welding pool. The base metal that near the fusion line is not completely melted, and the melting metal is grown to be a columnar crystal by the way of union growth, as shown in Figure.4(a). The second layer will keep on growing up in the same way as the dendritic growth on the first layer in Figure.4(b**).** A large number of equiaxial grains were found in the surface region of the welding joint. And the morphology is shown in Figure.4(c). This kind of change is related to temperature gradient (G) and solidification velocity (R). There is a large temperature gradient in the welding pool that G is very large while R is opposite in the bottom fusion zone in the process of arc surfacing, which result in the grain grow up rapidly in the form of dendrites. And G/R is close to 0 around the surface region, a certain amount of equiaxial crystals will be formed in the weld until G/R reach the critical value. Meanwhile there are surface tension, electric arc blowing force, gas power and the inhomogeneity of microelement in the process of welding, therefore, different parts of the welding pool correspond to different cold speed, which result in the final solidification microstructure is significantly changed.

Due to the welding heat cycle, the first layer is inside the welding pool with poor heat dissipation, therefore, it will have been tempered when the second layer of welding begins to melt, the dendrite of first layer is significantly larger than that of second layer although the two layers of weld solidified by the same way, as shown in Figure.4(a)(b).

Due to there is a large temperature gradient in cooling process, G/R reaches the critical growth condition of dendrite, the liquid metal is rapidly growing into a cylindrical dendrite along the semi-molten matrix grain. Solid phase is formed by solidified metal in the form of dendritic growth, the solid phase is surrounded by the liquid metal between the dendrite, which is obviously divided. A large number of alloys element segregate in this region due to the growth conditions are limited. The stability of austenite directly affects the martensite transformation process. Finkler and Schirra[11] presented an empirical formula based on the content of alloy element in metals to estimate the temperature of martensite transformation:

$$Ms = 635 - 475w_C - 17w_{Cr} - 33w_{Mn}$$

Ms is the starting temperature for martensite transformation, w_{C}, w_{Cr}, w_{Mn} is the content of C, Cr and Mn in austenite respectively. The formula indicates that the increase of alloy content in austenite can affect the temperature of martensitic transformation in varying extent. In this study, the contents of Cr and Mo elements in the microstructure of dendrite were sharply increased, and the change of C element was not obvious, as shown in Figure.5, the segregation of the alloy elements near the crystal boundary was described. It causes M_s decrease, so the austenite is more stable, and the residual austenite is formed near the end of the crystal boundary at last. While the martensite transformation is more likely to occur within the dendrite, and finally the martensite organization is formed.



(a) The dendrite of first layer (b) The dendrite of second layer (c) The equiaxed grains of surface

Figure.4 SEM image of different region of welding pool

3.2. Microhardness and wear test

Figure. 6 shows the microhardness distribution along the weld thickness, from the weld center to the matrix. According to the figure, the microhardness of the second layer weld is 774.2 HV, the hardness of the surface is improved greatly compared with the hardness of the base metal. Due to the second layer of the surfacing has the effect of tempering and recrystallization on the first layer, the hardness of grain is reduced slightly near the first layer. While the hardness of surfacing metal has a tendency of decrease along the thickness, and the microhardness near the fusion zone reaches the lowest point. It can be seen from Figure.4 that there is a number of residual austenite in the fusion zone and the structure is coarse leading to the decrease of hardness. The hardness trend gradually increases to a certain value due to the large amount of martensite in the quenching zone, the hardness of tempering martensite in the partial quenching zone is obviously lower than that in the quenching zone.

The change of surface wear rate of base metal and surfacing layer under different loads is shown in Figure. 7. It can be seen that the wear rate of the base metal and the surfacing welding layer under the 120N load is not very different, the abrasion resistance of the surfacing layer is significantly higher than that of the base metal until the load is higher than 150N. The wear rate of the base metal is more sensitive to load change. The abrasion resistance of the surfacing layer has a distinct advantage over the base metal under the high load. According to the Archard relationship[12], the higher the hardness is, the better wear resistance of the material is. In this study, the surfacing layer has higher hardness and shows excellent wear resistance.

Figure. 8 shows the SEM of surface abrasion of the base metal and surfacing layer under different loads. Under the load of 120N, the wear debris of base metal is small, individual wear debris is large

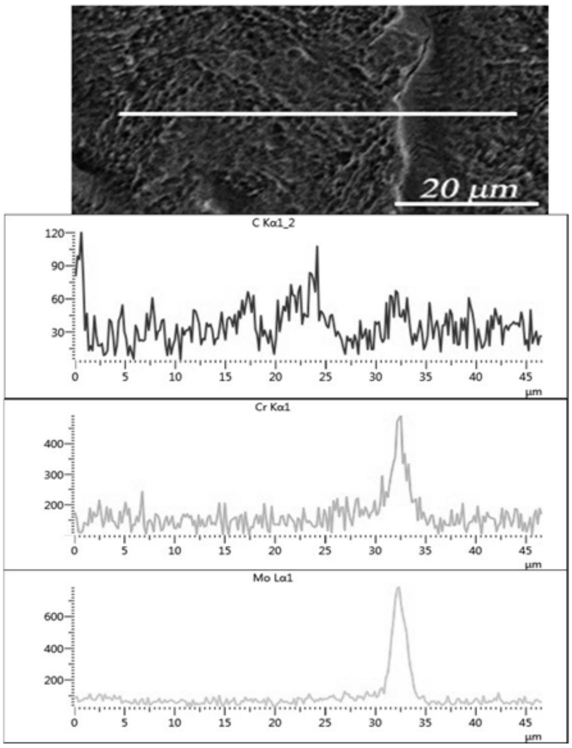


Figure.5 Element line scanning results of the dendrite of welding pool

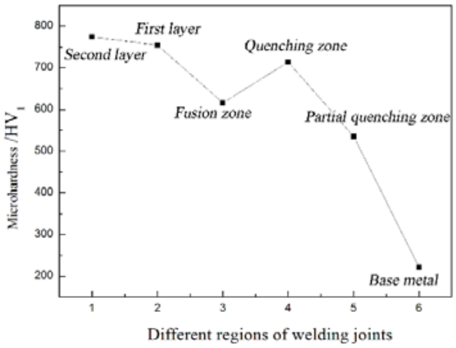


Figure.6 Microhardness of the weld thickness

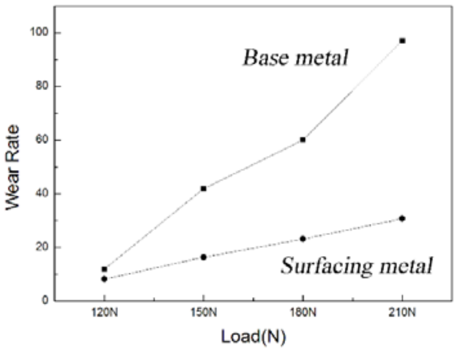
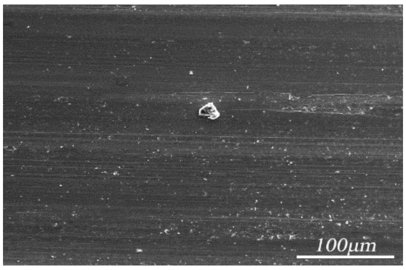
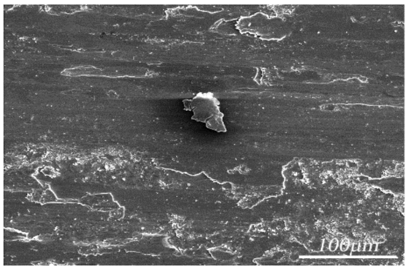


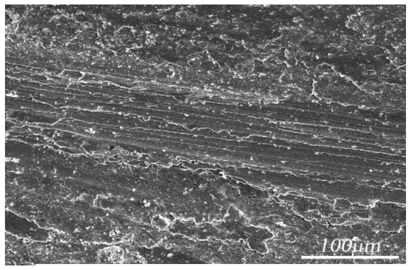
Figure.7 The variation of wear rate of base metal and surfacing metal under different loads



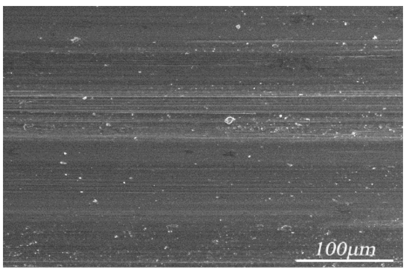
(a) Base metal of 120N



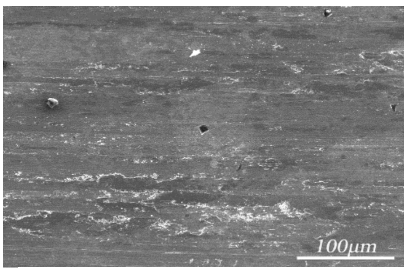
(b) Base metal of 180N



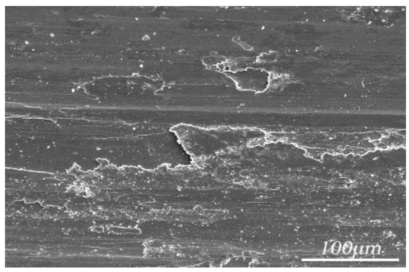
(c) Base metal of 210N



(d) Surfacing metal of 120 N



(e) Surfacing metal of 180N 180N



(f) Surfacing metal of 210N

Figure.8 Wear surface morphologies of base metal and surfacing layer under different loads and the wear surface is smooth, while there are some obvious scratches along the sliding direction, the wear mechanism is mainly abrasive wear. Under the load of 180N, the abrasion surface appears to be flaking with large wear debris, and there is obvious plastic deformation on the surface of the sample, therefore it shows the characteristic of adhesive wear. When the load is 210N as shown in Figure. 8(c), there is more wear debris and intense plastic deformation, while the oxygen content of wear debris and plastic deformation is high, oxidation plays an important role in wear.

It is similar to the surface of the base metal under the load of 120N that there are some obvious scratches in the surface of surfacing metal, the wear debris is fine and the amount of which is small, and the same abrasive wear characteristics are shown. Under the load of 180N, the wear debris is obviously clumped distribution, the size of the wear debris becomes larger and begins to fall off at the same time which show obvious characteristic of adhesive wear. The wearing surface appears to have obvious plastic deformation and a large amount of wear debris when the load reach 210N as shown in Figure.8(f). Similar to the base metal, the oxygen content of the abrasive and plastic deformation region is still high, which prove that has the characteristics of oxidative wear.

Due to the optimization of welding process, there is not a large amount of carbide particles in the surfacing, while C element are still abundant in martensite matrix, therefore, the hardness remains high. The addition of alloy elements improve the oxidation resistance and the stability of the tempering, the wear resistance is optimized accordingly.

4. Conclusion

1. The microstructures of the surfacing and quenching zone of die steel consisted of martensite and residual austenite, and the tempering martensite was dominate in the partial quenching zone..

2. The microhardness of the surfacing was 774.2 HV, which was about 100HV higher than that of base metal.

3. The wear mechanism of the surfacing was similar to the base metal under different loads, namely, abrasive wear at low load, oxidative wear and adhesive wear at high load.

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