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WELDABILITY OF HEAT-RESISTANT AUSTENITIC STAINLESS STEEL PRODUCED BY SINTERING

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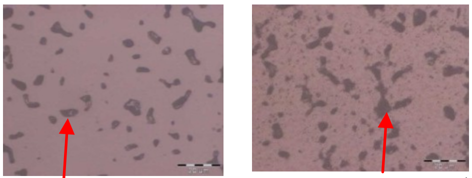
ABSTRACT
Increased use and production of sintered stainless steel components require more intense investigation of their weldability. Weldability of P/M parts requires additional analysis compared to wrought or cast metals due to their specificities in physical properties. Residual porosity and sintering parameters of the heat resistant stainless steels are factors that mostly affect not only properties of sintered parts, but also their weldability. In this regard, effect of sintering parameters on the weldability of the Nb-modified heat resistant stainless steel HK 30 is discussed in this paper. Comparison of solid state and fusion welding of sintered components was performed using sinter-joining and plasma welding. Microstructure of sinter joined area, solidification structure of melting zone and microstructure changes in heat affected zone were explored using metallographic techniques. Hardness distribution through fusion zone and heat affected zone was also analysed and presented in the paper.
Keywords: heat-resistant stainless steel, sintering, welding, sinter joining.

1. INTRODUCTION

Final characteristics of sintered austenitic stainless steels components are very dependent on the sintering parameters [1, 2, 3]. Thus, sintering conditions must be included in the weldability analysis of similar and dissimilar P/M stainless steels. Sintering temperature, sintering time, sintering atmosphere, heating and cooling rate are parameters that have significant influence on the final mechanical and physical properties of sintered stainless steel components [1,2,3]. Compared to wrought or cast, sintered stainless steels have residual porosity (figure 1.) that affects not only mechanical properties but also thermal conductivity, and consequently heat transfer during welding. Porosity shape (figure 1.), its quantity, distribution and trapped gases can influence properties of melting zone and heat affected zone.



a) b)

Figure 1. Microstructure of austenitic heat resistant stainless steel sintered at: a) H_2,1200 °C, 400 mbar b)N_2, 1200 °C, 400 mbar; [3]

Typical sintering atmospheres for stainless steels include hydrogen, hydrogen-nitrogen mixtures, dissociated ammonia, and vacuum [1,2,3]. Sintering temperature and sintering time mostly affect sintered porosity and final density, as well as intensity of material-atmosphere interaction. Sintering in hydrogen atmosphere gives highest densities and lowest amount of porosity, while carbon percent in steel is reduced, which affects mechanical properties [3] and weldability of stainless steel. Nitrogen containing atmosphere causes absorption of nitrogen, increasing of hardness [3] and strength of material, while weldability can be deteriorated. Outgassing during welding can result in excessive porosity formation in the weldment [2]. Welding of sintered components can be done by fusion welding, with or without filler material, and by solid state welding. Welding of lower density parts (<6,5 g/cm3) requires avoiding of molten weld metal and solidification stresses [2]. Components with densities <6.9 g/cm3 should be welded using processes with minimum volume of molten weld metal such as resistance projection welding and friction welding [2,4]. In addition to stresses and potential risk of cracks formation in HAZ, fusion welding brings inhomogeneity of mechanical properties and microstructure in the weldments (Figure 2). Laser, plasma and electron beam welding are processes that are constantly used for welding P/M components.

Sinter joining method, where joining of two components during sintering is performed, is a process which has multiple advantages. Complex shapes of MIM components can be done from more simple shapes [5], but intensity and direction of components shrinkage should be carefully analysed. For example, ferritic outer component will experience more intensive shrinkage than austenitic core, resulting in tight contact which permits diffusion between surfaces and formation of bond [1]. In this way, microstructural and chemical homogeneity can be achieved, joining without filler material and avoiding residual stresses, joining of dissimilar material, etc.

Weldability of sintered austenitic heat resistant stainless steels using solid state and fusion welding is analysed in this work. Effect of plasma heat input on solidification microstructure, characteristics of partially melted and heat affected zone of the Nb-modified HK 30 heat resistant stainless steel were experimentally studied. Also, effect of different sintering conditions on its weldability was discussed.

2. EXPERIMENTAL WORK

Comparision of solid state welding and fusion welding of the Nb-modified heat resistance stainless steel HK30 is presented in the experimental part of the work. Chemical composition of the steel is as follow: 24-26 % Cr, 19-22 %Ni, 1.5 %Mn, 1.3 %Si, 0.2-0.5 %C. Addition of 1,2 % Nb forms fine dispersed stable carbides and significantly increases strength of the steel. Sinter joining process was done in nitrogen atmosphere. Parts used in welding process were produced using metal injection molding technology (MIM). Part 1 (figure 3) was sintered prior to joining, in nitrogen atmosphere, temperature 1310 ^{o}C and nitrogen partial pressure of 400 mbar. Parts were cooled in the sintering furnace which resulted in very slow cooling rate. Part 2 was injection molded, catalytic debound in nitric acid and mounted on part 1. Plasma current was varied in two levels (35 A and 40A), with time of 1,7 s.

3. RESULTS AND DISCUSSION

During sinter joining process, at the temperature of 1310^{o}C and time of 3 h, joining of two components occurred at the same time with the sintering of component 2. Appropriate shrinkage was ensured using previously sintered part 1, where its shrinkage during sinter joining is negligible compared to part 2, whose shrinkage coefficient can reach up to 14%. Microstructure of joining zone is presented in Figure 3. In this case welding and sintering process was performed at the same parameters.

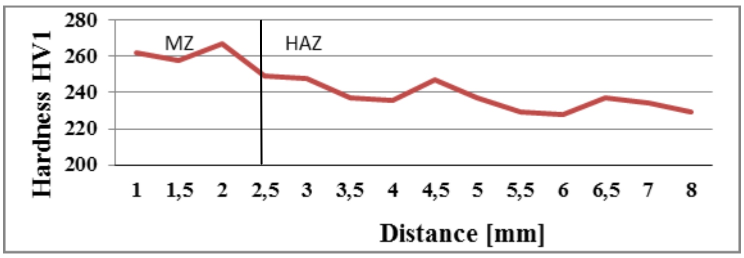


Figure 2. *Hardness distributions through cross section of melting zone (MH), heat affected zone (HAZ) and parent material*

Diffusion process took place between individual particles on part 2 and surface of part 1. Clear boundary between parts, except for differences in grain size, can not be observed at the joining area (Figure 3. a, b,c). Since part 1 was sintered prior to joining process, its time spent at temperature of 1310 ^{o}C was 6 h, which resulted in significant grain growth compared to part 2. Sinter joining in nitrogen atmosphere resulted in formation of some structural and chemical inhomogeneities. Absorption of nitrogen, especially through surface of parts and slow cooling after sinter joining resulted in excessive creation of lamellar nitride structure at the ends of bonding line (figure 3. d,f). On the other hand, microstructural and chemical inhomogeneities can not be noticed if sintering and sinter joining are performed in hydrogen or argon atmosphere.

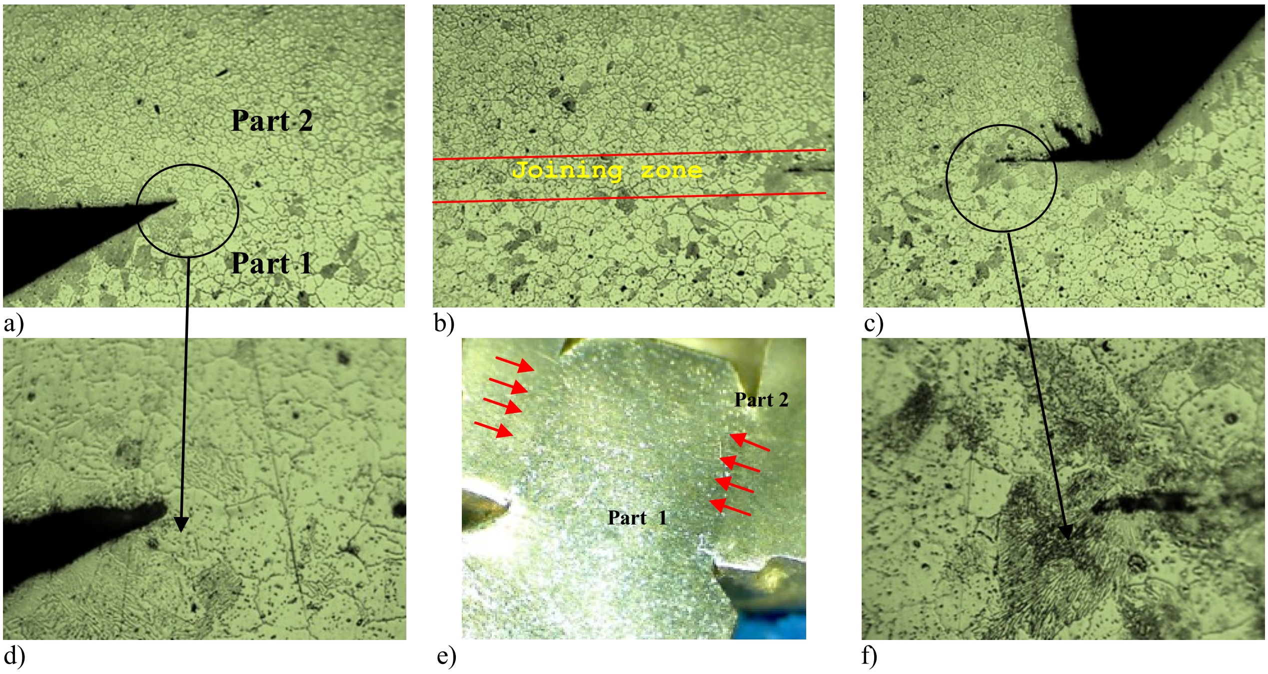


Figure 3. Microstructure of sinter joined Nb-modified HK30 heat resistant stainless steel: a), b),c) joining area-100x, d), f) ends of joining zone -500x, e)shrinkage direction during sinter joining

Effect of plasma heat input on microstructure of heat affected zone, partially melted zone and fusion zone is presented in figure 4. It can be seen that parent material consists of austenitic microstructure with distributed carbides and residual porosity. Also, lamellar structure of chromium nitrides in austenite is well distinguished. Heat affected zone in both cases (35A, figure 4. a,b,c; 40A, figure 4. d,e,f) shows austenitic microstructure with discontinuous lamellas of nitrides. This can be explained by high temperature of HAZ and dissolving of nitride lamellas in austenite.
Grain boundaries in heat affected zone are significantly less emphasized compared to parent material. As grains approach to melting zone, lamellar structure of nitride formed after sintering becomes more dashed (figure 4, b, e arrow 1-2) and disappears in partially melted zone, where fully austenitic microstructure can be observed.
Austenite in melting zone and HAZ is significantly more saturated with carbon and nitrogen, showing greater hardness for about 13% compared to parent material (Figure 1). Fine precipitate are formed after remelting and fast cooling, which also contributed to hardness increase. Significant increase of hardness is not expected if sintering of parent material is done in hydrogen, argon or vacuum. In this case, nitrogen absorption and hardening of steel is avoided. Hydrogen atmosphere causes reduction of carbon percent [3], as well as decreasing of solid solution hardening and precipitation hardening of the steel.
In addition, solidification behaviour of alloy during welding is very dependent on chemical composition obtained after sintering. Thus, adding of nitrogen changes solubility of carbon in austenite, affecting final microstructure and mechanical properties of weld metal. It is important to notice that grains in heat affected zone in both cases (35A, 40A) did not grow significantly. Residual porosity, especially bigger pores concentrated in grain boundaries, acts as obstacles to the movement

of grain boundaries, which resulted in insignificant changes in grain size. Weld metal solidifies at the grains which were partially melted, and keeps the orientation of the parent grain during solidification (figure 4. f).

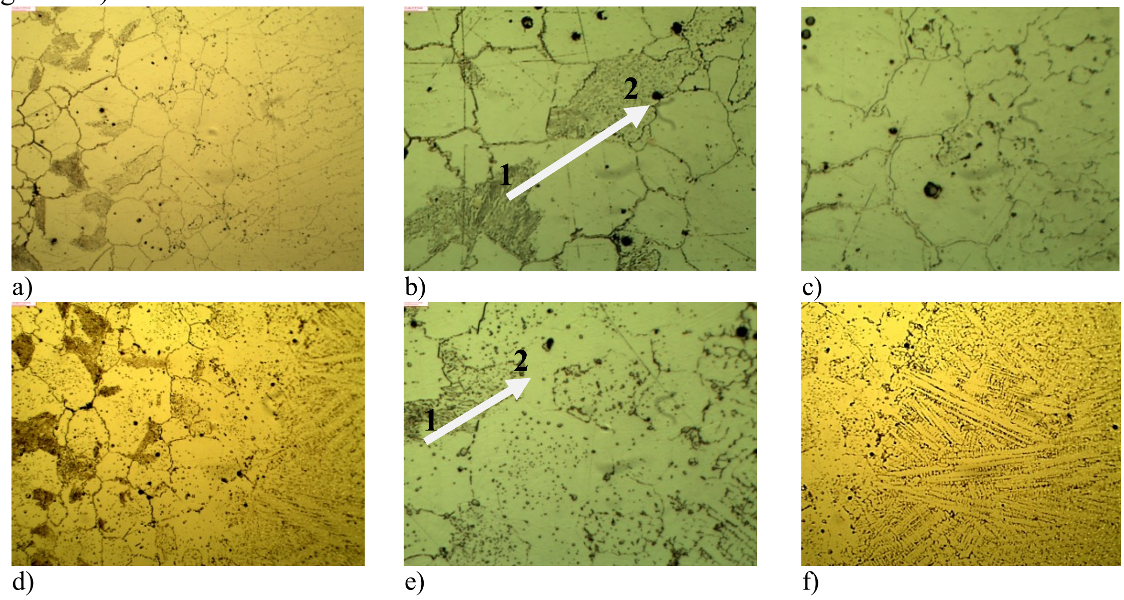


Figure 4. Effect of plasma heat input on microstructure of melting zone and HAZ of Nb-modified HK 30 heat resistant stainless steel: a) HAZ, 40A, 200x b) HAZ, 40A, 500x c) partially melted zone, 40A ,500x d) HAZ, 35A, 200x, e) HAZ, 35A, 500x f) melting zone, 35A, 200x.

4. CONCLUSION

Properties of sintered stainless steels are very dependent on the sintering parameters. Thus, sintering parameters must be included in weldability analysis of heat resistant stainless steels. Reducing of residual porosity and selection of proper sintering atmosphere are factors that can be exploited to improve weldability of sintered components. Fusion welding significantly changes properties of melted zone and heat affected zone compared to parent material. Dissolution of precipitates formed during sintering and significantly increasing of hardness can be expected if fusion welding is used. On the other hand, sinter joining gives the bond with characteristics completely identical with parent material. Shrinkage direction and intensity must be carefully analysed before using sinter joining method. Differences in some zones of joining area, and formation of precipitates is a result of prior processing of components or interaction with sinter-joining atmosphere.

5. ACKNOWLEDGEMENTS

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