



RESEARCH ARTICLE

EXPERIMENTAL INVESTIGATION OF WELD JOINTS BETWEEN SINTERED Nb MODIFIED HK30 STAINLESS STEEL AND WROUGHT/CAST STAINLESS STEELS

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Manuscript Info

Manuscript History

Received: 05 September 2021

Final Accepted: 10 October 2021

Published: November 2021

Key words:-

Sintering, Atmosphere, Weldability,
Dissimilar Metal Welding, Porosity

Abstract

Very important property of powder metallurgy parts is ability to join to components produced by different manufacturing technologies or dissimilar materials. Properties of powder metallurgy Nb modified HK30 components are highly influenced by conditions applied during sintering. Weldability of sintered components can be improved using favorable sintering conditions. In this regard, effect of sintering parameters on fusion weldability of Nb modified HK30 is presented in this paper. Investigation of weld joints between HK30, produced by different sintering conditions, and cast HK30 stainless steel is performed. In addition, examination of welds between sintered HK30 and wrought 304 stainless steel is also performed. Microstructural examination and hardness testing of fusion zones and heat affected zones were done for different combinations of base material.

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Introduction:-

Unique properties of parts produced by powder metallurgy caused expansion of this manufacturing technology in production of parts for various industrial applications. Some of advantages of powder metallurgy technologies compared to other manufacturing technologies are: efficient material utilization, near net shape production, ability to process very demanding materials, easier achievement of desired microstructure, production of porous components etc. One of the very important factor for some application of PM parts is ability to join to components from dissimilar materials, produced by powder metallurgy or other manufacturing technologies. Residual porosity and reduced thermal conductivity of sintered components affect heat transfer during welding. In addition to the effect on physical properties of material, residual porosity can contain entrapped gases which can adversely affect weldability of the PM components. Austenitic Nb modified stainless steel HK 30 sintered in N₂ atmosphere can contain more than 0.5 % [1] of nitrogen, which is released during fusion welding and causes porosity in fusion zone (Figure 1.). Application of sinter joining process on this steel resulted in the weld joint with characteristics almost identical to the base material, because the melting is avoided [2]. On the other side, nitrogen increases hardness and strength of the steel [1, 3]. Grain structure of sintered base material has also an impact on solidification behavior of fusion zone during welding. Sensitivity of fusion zone to hot cracking depends on its structure, whereas fine grains of fusion zone are more resistant than coarse columnar structure [4].

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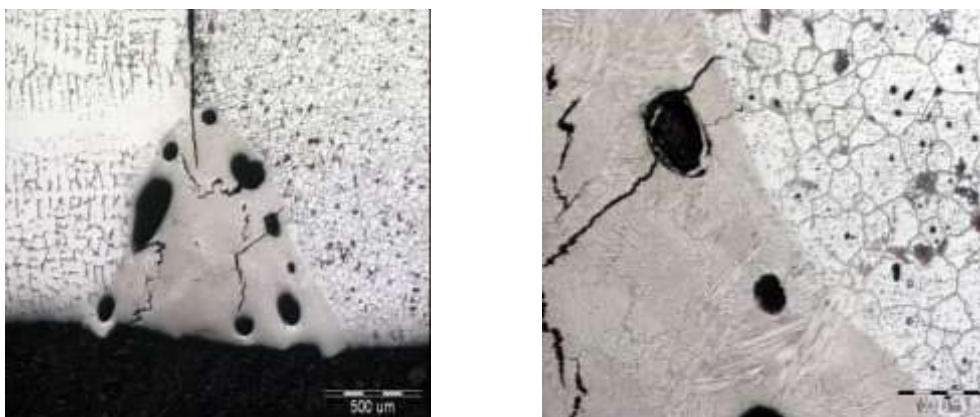


Figure 1:- Laser weld between HK30 stainless steel sintered in N₂ atmosphere at temperature of 1310 °C and HK30 stainless steel produced by centrifugal casting.

Sintering in hydrogen and argon results in more ductile material, lower hardness and strength, lower percent of porosity and reduction of carbon and nitrogen percent [1,3]. If material has high amount of porosity with reduced contact area between particles, thermal stresses in heat affected zone can cause cracking [5]. Residual porosity, carbon percent, nitrogen percent and grain structure of sintered components are factors which significantly depend on sintering parameters. Thus, sintering parameters must be taken into account during weldability analysis of sintered components. In this regard, investigation of weld joints between sintered Nb modified HK 30 stainless steel (sintered steel in following text) and wrought/cast stainless steels for different sintering conditions were performed in this work. Experimental probes were done using laser and plasma welding processes.

Experimental work

Metal injection molding technology was used for production of sintered components (Table 1.). Sintering was done in three different atmospheres and two levels of temperature. Primary debinding and residual binder debinding were performed by catalytic debinding and thermal debinding processes, respectively. Sintering was done in hydrogen, nitrogen and argon atmosphere at temperatures of 1200 °C and 1310 °C. First part of experimental work refers to examination of fusion zone, partially melted zone and heat affected zone of laser weld joint between sintered and cast components. In addition, investigation of plasma weld joint between component sintered in dissociated ammonia and wrought 304 austenitic stainless steel was performed.

Table 1:- Typical chemical composition after sintering niobium modified HK30 steel.

C (%)	Cr (%)	Ni (%)	Si (%)	Nb (%)	Mn (%)	Rest (%)	Fe
0,2-0,5	24-26	19-22	0,75-1,3	1,2-1,5	<1,5	<2	Balance

Metallographic examinations and hardness testing of base materials, heat affected zone, partially melted zone and fusion zone were done for all experiments. Hardness profiles (Vickers method) across the weld, for different combination of base material, are presented.

Results And Discussion:-

Laser welding of parts sintered in different sintering atmospheres were done at the beginning of experimental work. Microstructures presented in the Figure 2. refer to fusion zone and heat affected zone of part sintered in argon atmosphere and temperature of 1200 °C. Despite the high percent of porosity of base material, crack free fusion zone and crack free heat affected zone can be observed. As a consequence of argon released from the pores during melting, formation of isolated pores can be expected in fusion zone.

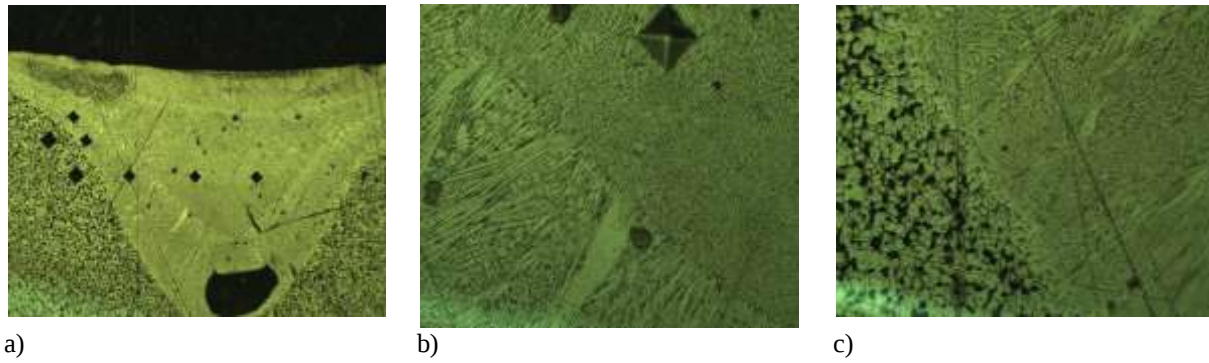


Figure 2:- Laser welded HK 30 sintered in argon atmosphere at 1200 °C: a) welded joint, b) fusion zone, c) heat affected zone.

Cooling rate of melt decreases as distance from fusion line increase, which causes different morphology of fusion zone (Figure 2. a, b). The lack of material in the fusion zone may be the result of the wicking of the melt by the porous base material. This problem is particularly pronounced as the percentage of porosity in the base material increases. Average hardness of steel sintered in argon and temperature of 1200 °C is 165 HV. Sharp increase in hardness is observed in the fusion zone. Increase of density, as a consequence of melting, contributed to hardness increase to an average value of 250 HV (Figure 3.). Parts sintered in nitrogen atmosphere at temperature 1200 °C showed average hardness of 220 HV, while the average hardness of the fusion zone is 230 HV (Figure 3.). Strengthening of material due to nitrogen absorption from sintering atmosphere resulted in higher hardness. The release of nitrogen during welding causes the formation of very porous fusion zone, weak weld and appearance of cracks (Figure 1.). Nitrogen in sintered steel may be in form of solid solution, nitrides and entrapped in pores [6]. The best weldability was achieved during welding of parts sintered in hydrogen atmosphere. Fusion zone and heat affected zone are almost without porosity for both 1310 °C and 1200 °C cases. Hardness across the plasma weld joint of steel sintered in H₂ and temperature of 1310 °C, varied from 175 HV in base material to 196 HV in fusion zone. However, reduced mechanical properties of steel sintered in hydrogen atmosphere may be the limiting factor for some applications of this steel.

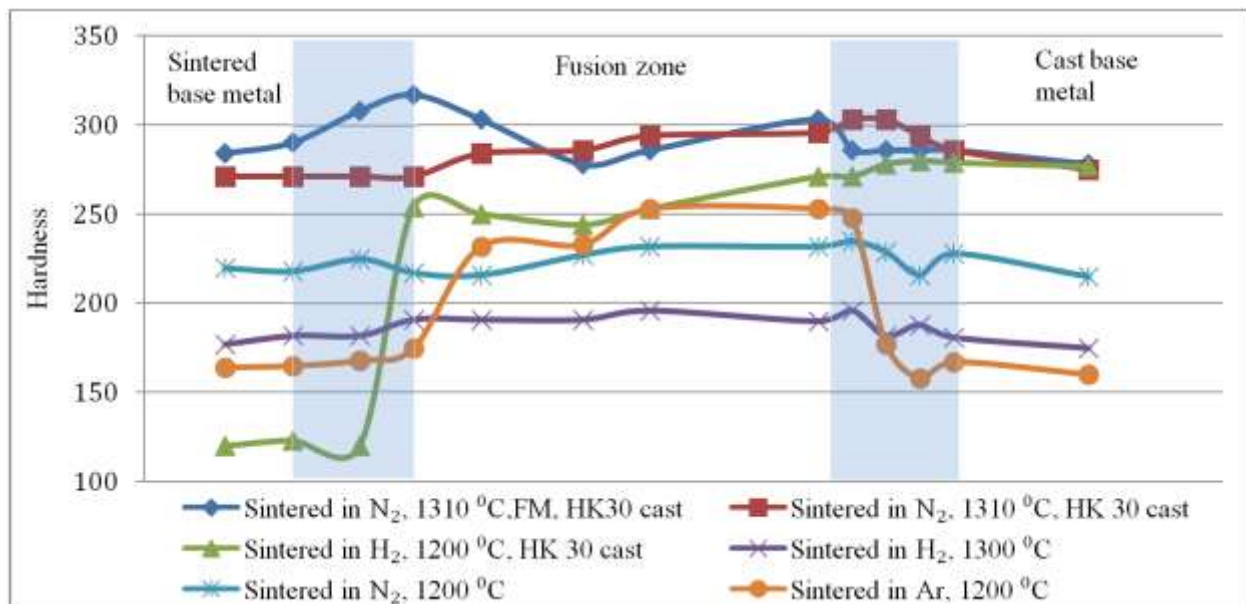


Figure 3:- Hardness profiles across the welds.

Characteristics of fusion zone for weld joint between sintered and cast stainless steel strongly depend on atmosphere and temperature used during sintering (Figure 4. and Figure 5.). Lower sintering temperature and high percent of porosity for parts sintered in N₂ showed very porous fusion zone. The application of filler material, in this case, reduced the porosity in the fusion zone. Despite to high percent of porosity, parts sintered in hydrogen and argon at

temperature of 1200 °C showed very good weldability. Increasing of sintering temperature and reduction of porosity after sintering strongly improves weldability of steel.

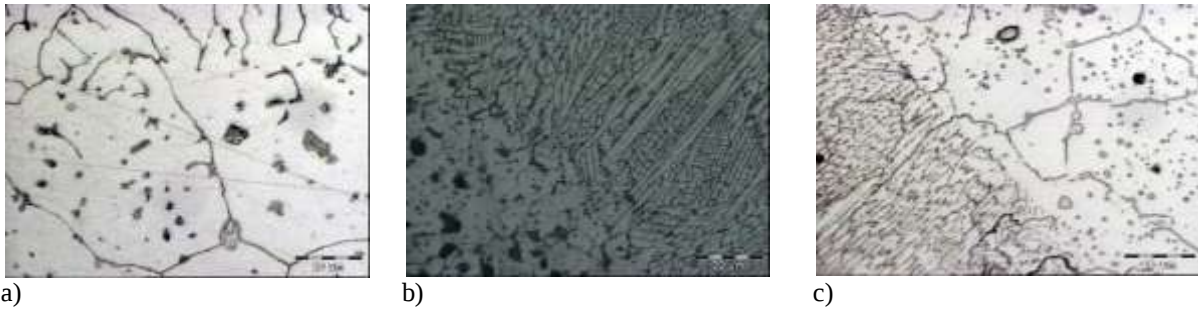


Figure 4:- Partially melted zone of laser welded: a) HK30 sintered in H₂-1310 °C, b) HK30 sintered in Ar-1200 °C and cast HK30, c) HK30 sintered in N₂-1310 °C and cast HK30.

Growth of grains in fusion zone starts from partially melted grains at the fusion line (Figure 4.). The size of formed grains depends on base material grain size. It means that grain size of sintered components has very important role during weld metal solidification. Parts sintered in H₂ and temperature of 1310 °C have the largest grains, causing very coarse weld metal structure. Finer grains, as observed in all parts sintered at 1200 °C, showed finer structure of fusion zone (Figure 4.). Also, parts sintered in N₂, showed smaller grains giving finer structure of melt zone compared to parts sintered in H₂. Fusion zone structure in the cast side of the weld is significantly different from structure in sintered side. Grain growth in the cast side of the weld starts at the dendrites formed during cooling of austenitic stainless steel after casting process.

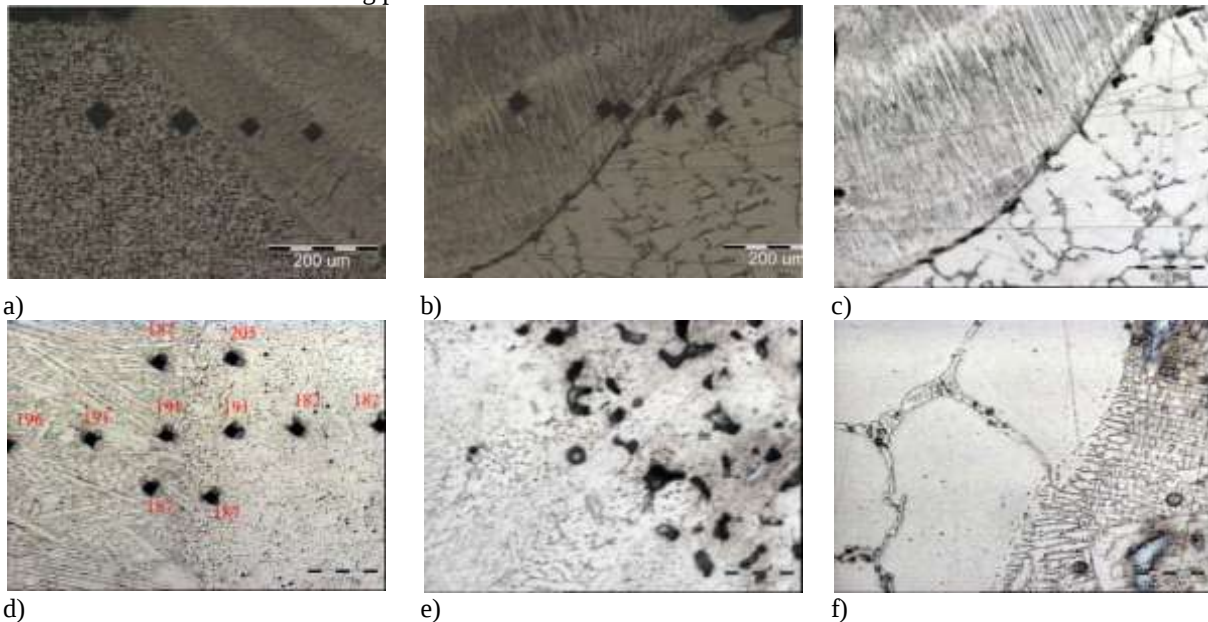


Figure 5:- Microstructures of laser welded joint between: a) HK30 sintered in H₂-1200 °C and cast HK30, sintered side, with FM, b) HK30 sintered in H₂-1200 °C and cast HK30, cast side, with FM, c) HK30 sintered in H₂-1200 °C and cast HK30, transition zone in cast side, with FM, d) HK30 sintered in H₂-1310 °C and plasma welded, e) HK30 sintered in Ar-1200 °C and cast HK30, sintered side, f) HK30 sintered in Ar-1200 °C and cast HK30, cast side.

Significant hardness variations are not observed across the weld joint between steel sintered in nitrogen atmosphere at temperature of 1310 °C and cast steel. Average hardness of cast steel was 282 HV, while fusion zone and sintered steel were 288 HV and 283 HV, respectively. Slightly refined structure of fusion zone was observed when filler material is used. Differences in thermal conductivity of the porous sintered and cast component affected the heat distribution during welding which caused differences in fusion zone geometries. Geometry of fusion zone is extended to sintered side of the weld.

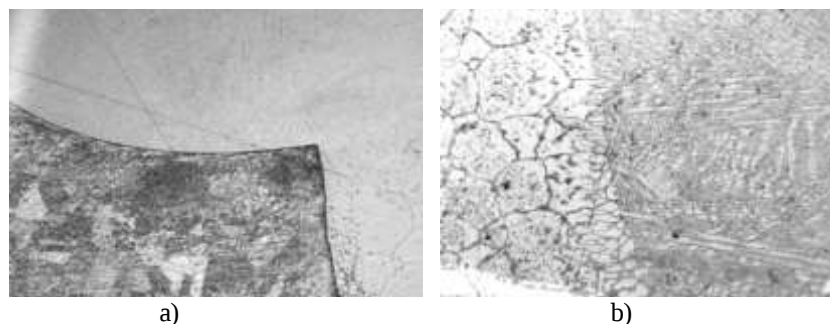


Figure 6:- Microstructure of plasma welded joint between sintered HK30 steel and 304 austenitic stainless steel: a) weld joint b) fusion zone.

As seen before, very good weldability was achieved using hydrogen as sintering atmosphere, even in case when very low density parts were welded. Large hardness variations through weld joint between steel sintered at 1200 °C (H_2) and cast steel was observed. Hardness varied from 125 HV in sintered side up to 280 HV in fusion zone and cast base material. Low density of sintered part and reduced carbon contents are responsible for reduced hardness in sintered side. Taking into account poor mechanical properties of parts sintered hydrogen and argon and low weldability of N_2 sintered parts, mixture of H_2 - N_2 atmosphere can be used in order to fulfill the most requirements. In this regard, plasma welding of HK30 steel sintered in mixture of H_2 - N_2 to wrought 304 austenitic stainless steel is investigated (Figure 6.). Fusion zone and heat affected zone are without porosity and cracks. Hardness of 304 base material is 196 HV, while average hardness across the fusion line and fusion zone are 215 HV and 219 HV, respectively. Average hardness of heat affected zone of sintered base material is 180 HV.

Conclusion:-

Properties of weld joints between sintered HK 30 stainless steel and wrought/cast stainless steels are very dependent on parameters applied during sintering. Residual porosity, absorbed gases and grain structure are factors which have high influence on weldability of sintered component. Also, grain structure of sintered base material affects solidification process of fusion zone. Refinement of fusion zone structure is observed after welding of sintered components with finer grain structure. Differences in thermal conductivity of the porous sintered components and cast component caused differences in fusion zone geometries.

Sintering in nitrogen atmosphere resulted in improved mechanical properties of sintered steel, but reduced weldability of steel. Lower sintering temperature and high percent of porosity for parts sintered in N_2 showed very porous fusion zone. Porosity in fusion zone appears due to nitrogen released from steel during welding. Steel sintered in hydrogen and argon atmosphere showed very good weldability, but reduced mechanical properties can limit the application of this steel for some operation conditions. Porosity free and crack free weld joint between HK30 steel sintered in H_2 - N_2 atmosphere and 304 stainless steel are observed.

References:-

1. Samir Butković, Mirsada Oruč, Emir Šarić, Muhamed Mehmedović, Sulejman Muhamedagić, Investigation of hardening of heat resistant stainless steel during sintering process, Conference: 1st MME SEE 2013, 1st Metallurgical & Materials Engineering Congress of South-East Europe, May 2013, Belgrade, Serbia.
2. Samir Butković, Muhamed Mehmedović, Emir Šarić, Weldability of heat-resistant austenitic stainless steel produced by sintering, Journal of Trends in the Development of Machinery and Associated Technology Vol. 20, No. 1, 2016, ISSN 2303-4009 (online), p.p. 41-44.
3. Samir Butković, Mirsada Oruč, Emir Šarić, Muhamed Mehmedović, Effect of sintering parameters on density, microstructure and mechanical properties of niobium modified heat resistant stainless steel GX40CrNiSi25-20 produced by mim technology: *Materiali in tehnologije / Materials and technology*, Volume 46 (2012) 2, pp.185–190.
4. S. Lampman, Weld Integrity and Performance, Weld Solidification, ASM International, 1997.
5. C. Selcuk, S. Bond and P. Woollin, Critical Review of Joining Processes for Powder Metallurgy Parts, Paper presented at Euro PM 2008 Congress and Exhibition, Mannheim, Germany, 29 Sept - 1 Oct 2008.
6. Erhard Klark, Prasan Samal, Powder metallurgy stainless steel, processing, microstructure and properties, ASM International, Ohio 2007.