Investigation of dissimilar joining ferritic stainless steel 430 to austenitic stainless steel 304 by transient liquid phase bonding process

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Abstract

In this study, dissimilar joining of ferritic stainless steel 430 with austenitic stainless steel 304 with BNi-2 Interlayer was investigated by the joint process of the transient liquid phase under inert gas. The joint process was carried out at a constant temperature of 1120°C and at four storage times of 30, 60, 120 and 180 min. To investigate the microscopic structure of the optical microscope, a scanning electron microscope and an X-ray diffraction spectroscopy were used to investigate the mechanical properties of the microhardness and stretching device. At 120 min of storage, due to the proper penetration of the interlayer into base metals and the formation of intermetallic compounds, the hardness in the four dough areas, mashi zone, heat affected zone, joint and the base metal interface reached its maximum. The maximum shear strength was also achieved at the same temperature and storage time, equal to 860 kPa. during storage, 180 min, although proper penetration of the interlayer was performed in base metals, but due to an increase in the diameter of the ferritic stainless steel grains from 10 to 35 μm and the austenitic steel ranged from 7 to 29 μm, relative strength and hardness were reduced.

1. Introduction

Ferritic stainless steels are used in various industries due to corrosion and oxidation resistance at high temperatures. Austenitic steels are used in various industries and at nuclear power plants at high temperatures. Due to the properties and common use of these two types of steel, joining of these two categories is inevitable. The transient liquid phase (TLP) process is one of the diffusion welding processes. In this process, the components joint by the interlayer, due to the presence of melting point reducing elements, such as boron, silicon and the like, have a melting point lower than the base metals, joint to each other and provide a seamless joint. In this process, the final bond produced in terms of chemical composition and physical and mechanical properties can be equal to that of base metals. This joint method is also used in the joint of alloy steels [1-4]. Atabaki et al.

examined the joint of austenitic stainless steel 304 with the copper interlayer between and the process of jointing the transient liquid phase and, after joint, he did not observe any eutectic composition in the joint [1]. Garsia et al. investigated the effect of silicon nanoparticles on 304 steel welding with the TLP process. In this study, the BNi-9 nickel base foil was used as an interlayer material. Studies have shown the penetration of silicon nanoparticles in the boundaries and changes in mechanical properties and structure. The induced silicon nanoparticles have led to the development of a less eutectic structure in the melted area [2].

Balasubramanian investigated the joint of austenitic stainless steel 304 to Ti6Al4V alloy with the silver interlayer in the TLP process. The creation of intermetallic compounds at the site of the joint resulted in a sharp reduction in the shear strength. As the storage time increased, the strength was significantly reduced and no bond was established at the joint, due to which a large fraction of

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discontinuities was reported [3]. Ozan et al. investigate of ferritic stainless steel 430 to cast iron with the copper interlayer by using the joint process of the transient liquid phase. After the joint, both metal and steel foundations of carburization and Chromation were observed. The best mechanical and metallurgical properties were obtained at a binding temperature of 1100°C and maintained for 20 min [4]. In this study, the joining of ferritic stainless steel 430 to austenitic stainless steel 304 was investigated using a BNi-2 interlayer in a transient liquid phase and in the inert gas environment at a temperature of 1120°C and at specific times to determine suitable jointing conditions.

2. Materials and methods of research

The ferritic stainless steel 430 and austenitic stainless steel 304 were used as a base metal and the BNi-2 nickel base foil was used as the interlayer due to the similarity of its chemical composition with the base metals and the melting point of the base metal. Tables 1 and 2 show, respectively, the chemical composition and mechanical properties of base metals, and Table 3 shows the chemical composition of the interlayer.

Base metals in $10 \times 10 \times 6$ mm were cut using a wire cut machine. The cutting surfaces of all parts were completely polished and to eliminate any possible contamination, including rust and oil, all parts were washed with ultrasonic technique in acetone solution at 50°C for 30 min. Then, the parts with the BNi-2 interlayer with 20 μm on each other and placed inside the holder or fixture in a hot-plate steel. The retainer was designed to keep the parts together and exert a slight pressure during the jointing process. To study the effect of time on the process of transient liquid phase, four storage periods of 30, 60, 120 and 180 min and temperatures of 1120°C were used for joint. The heating rate and cooling of the furnace are the same for all specimens, with a heating rate of $10°C \cdot min^{-1}$ and a cooling rate of $2°C \cdot min^{-1}$.

After the joint, the specimens were cut off by the wire cut and in order to check their microstructure, after scouring the surface, the parts were etched with a 2% solution of Nietal for ferritic steel and 5% for austenitic steel. Electro etch was used to etch samples. The storage time of the samples in etch solution for ferritic steel was 2 min and for austenitic steel was 5 min. The surfaces prepared by optical and electron microscopy were studied for microstructure study. Also, Image-j software was used to measure the mean diameter of grains.

In the study of mechanical properties, a Vickers microstructure test with a force of 100 gr and a time of 10 s and a minimum of 50 μm from each other was performed by the KOOPA-X1500. Also, for measuring shear strength, a universal machine with a pulling speed of 2 mm·min^{-1} was used.

Table 1. Chemical composition of ferritic stainless steel 430 and austenitic stainless steel 304 (wt%).

Steel	Chemical Combination						
	C	Cr	Si	Mn	Ni	P	S
Ferritic stainless steel 430	0.13%	0.18%	0.75%	1%	8%	0.04%	0.3%
Austenitic stainless steel 304	0.08%	18%	1%	2%	8%	0.04%	0.03%

Table 2. Mechanical properties of ferritic stainless steel 430 and austenitic stainless steel 304.

Steel	Mechanical properties			
	Surrender strength (Ksi)	Tensile strength (MPa)	Elongation (%EL)	Hardness (HV)
Ferritic stainless steel 430	380.20	515.37	26.80	195
Austenitic stainless steel 304	388.42	541.78	26.40	170

Table 3. Chemical composition of the interlayer (wt%).

Ni	Si	B	Ti	Fe	S	P	Cr	O	Z	Co	C
82.5%	4.2%	2.98%	0.01%	2.91%	0.001%	0.005%	7.81%	0.02%	0.01%	0.02%	0.02%

3. Results and discussion

3.1 Microstructure study

Figure 1 shows an optical microscope from base metals, ferritic stainless steel 430 with ferrite grains and austenitic stainless steel 304 with austenite grains prior to bonding. The average diameter of the grains is 10 and 7 µm, respectively, for ferritic and austenitic stainless steel.
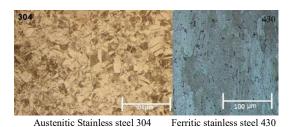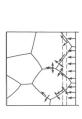

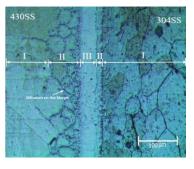Austenitic Stainless steel 304   Ferritic stainless steel 430

Figure 1. Crystal structure of base metals before the joint.

In Figure 2, the structure of the samples is shown after the joint at 1120°C and for 30 min. As it is seen, a suitable joint by transient liquid phase between the ferritic stainless steel 430 and the austenitic stainless steel 304 with the BNi-2 interlayer was created, and the base metal regions (I), under the influence of the penetration (II) and the interlayer (III) well defined. As you can see, the intrusive region at the austenitic stainless steel side is smaller and more uniform than the intrusive region in ferritic stainless steel. The interlayer's penetration on the ferritic side of the grain boundary is well defined as the rapid defibrillation paths. In the interlayer region, a small amount of the interlayer eutectic remains, requiring an increase in storage time for complete removal.

Figure 2. The microstructure of the joint zone at 1120°C and 30 min.

As the increases storage time, there is a great chance for the interstitial atoms to penetrate further. Figure 3 shows the microstructure of the junction at a temperature of 1120°C and at 60 min of storage. At this time, the atoms of the interlayer elements that penetrated and accumulated in the boundary of the grains of Figure 2 also penetrated into the grain, and the homogeneous and monophasic homogeneity of the grains was observed.

Figure 3. The microstructure of the joint zone at a temperature of 1120°C and 60 min.
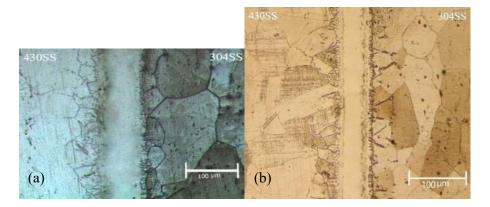
According to Figure 4, with increasing the storage time to 120 and 180 min, the interconnection and homogenization of the interlayer with the base metals increased and the grain diameter increased simultaneously. At the commencement of the joint sealing process, the joint was equal to the thickness of the interlayer strip of 20 µm, but as shown in Figures 2, 3 and 4, after the bond joint, the penetration of the alloying elements from the interlayer to the base metal and the joint expansion of the joint. Figure 5 shows the image of the electron microscope and the linear spectral analysis of the joint of the case at a temperature of 1120°C and a time of 120 min. Nickel elements, silicon and other alloying elements penetrate the base metal into the interlayer. Due to having an atomic radius less than an angstrom (0.97 Å) has the highest penetration distance. The penetration of alloying elements such as nickel in base metals is also appropriate as the penetration distance of this element is about 50 µm in ferritic stainless steel and 30 µm in austenitic stainless steel. Nickel is an element of austenitic and austenite stabilizer. In fact, austenite is a phase that stays stable with nickel. Mainly, in austenitic steels, nickel is used to neutralize the chromite ferrite effect. For this reason, diffusion of nickel into the austenitic steel is more than ferritic steel.

Figure 6, shows the dispersion of a Nickel element in a metal base. As you can see, the amount of nickel in austenitic stainless steel is higher than

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ferrite stainless steel. Nickel is austenite stabilizer and the degree of nickel penetration in austenitic stainless steel is higher than ferrite stainless steel.

Figure 7 shows the variation in the diameter of the average grain size with increasing storage time. As it can be seen, at a constant temperature of 1120°C, with increasing storage time at this temperature, the average diameter of the seeds increased. It is also noticeable that the hardness of

ferritic stainless steel is higher than austenitic. The results obtained from studies by other researchers such as Saida et al. [5] are in good agreement with the results obtained in the above study in the discussion of increasing the diameter of grains with increasing storage time. In studies by Saida et al., it has been observed that increasing the storage time of nickel at constant temperature increased the average diameter of the grains.

Figure 4. Joint microstructure (a) Temperature of 1120°C and 120 min of storage time; (b) Temperature of 1120°C and 180 min of storage time.
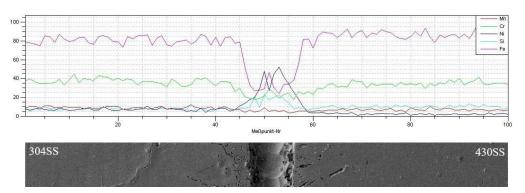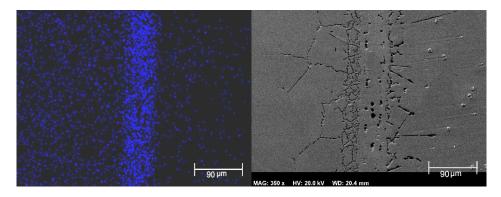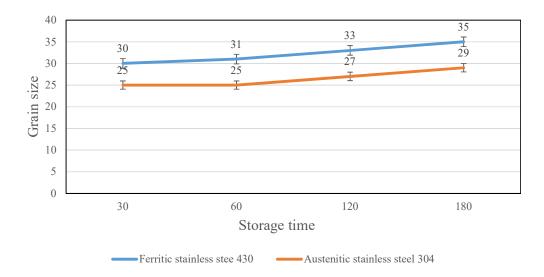

Figure 5. Joint line scan.

Figure 6. The amount of nickel element dispersion in the joint: (a) The amount of nickel element dispersion in base metals, (b) The SEM image of joint.

Figure 7. Density changes in grain relative to the storage time of 30, 60, 120, and 180 min at a constant temperature of 1120°C.
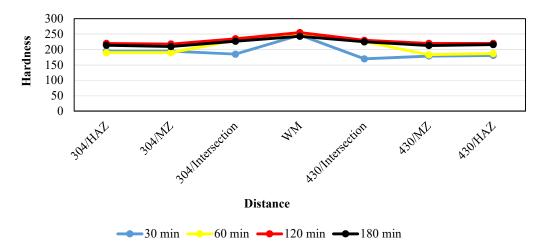
3.2 Hard check

Figure 8 Shows The hardness values of the heat affected zone, mashi zone, and the base metal and interlayer interface between the ferritic stainless steel 430 and the austenitic stainless steel 304 with a BNi-2 interlayer at 1120°C and 30, 60, 120, and 180 min. The hardness of the base metal before the joining action for ferritic stainless steel is 195 and in austenitic stainless steel is 170 wickers. The highest degree of hardness in the different bonding areas is 120 min. In view of the penetration and distribution of the elements around the joint line, the existence of intermetallic compounds Ni2.9Cr0.7 [2] and possibly C32M6 carbide [6] increases the hardness of these regions, but with a further increase in storage time to 180 min, the hardness slightly decreased. This hardness can be due to the increased diameter of the seeds, the dissolution and elimination of the alloy compounds formed by the high storage time. In a research by Balasubramanian on the jointing of austenitic stainless steel 304 to the titanium, it has been shown that with increasing storage time at constant temperature, the hardness increased, but with increasing time the hardness decreased [3]. In another study by Veverkova et al. on the Hans 230 alloy joint, it has been observed that this reduction was due to the elimination of double borders and the elimination of carbides [7].

The measured hardness values of joining are presented in Figure 9. According to these values, higher hardness value is related to the junction part.

As mentioned, the increase of hardness is related to the presence of the formation of hard phase into the junction part. The formation of hard-phases can be attributed to the high volume of alloy elements, time and sufficient temperature for the formation of these compounds.

3.3 Shear strength

Table 4 shows the results of shear strength of the ferritic stainless steel 430 to austenitic stainless steel 304 joint with BNi-2 interlayer at 1120°C and 30, 60, 120, and 180 min. As it can be seen, increasing the storage time from 30 min to 120 min indicates a shear strength of 710 to 860 kPa, respectively, which is due to the increase in strength due to sufficient time for the penetration of the elements and the formation of metal compounds, but with an increase in storage time of up to 180 min, the shear strength relatively reduced to 820 kPa. This decrease is due to an increase in the diameter of the grains and the dissolution and removal of intermetallic carbides and compounds. As can be seen from Figure10, it is clear that, at the same temperature, the amount of shear-strenght is enhanced with increasing of holding time. The maximum value of shear-strenght is observed at holding time of 120 min. With further increase in holding time, the value of shear- strenght has decreased slightly. This can be attributed to the dissolution of formed carbides at the junction.

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Figure 8. Hardness of different dough areas, mashi zone, heat affected zone, seamless joint at a temperature of 1120°C and storage time of 30, 60, 120, and 180 min.
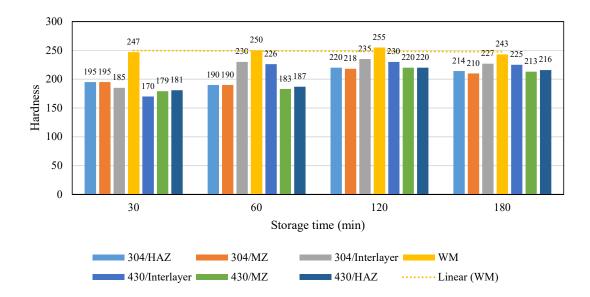

Figure 9. The statistical chart of hardness values of junction.

Other researchers have also pointed out the same reasons for shear strength changes with a change in storage time [3,7].

In order to investigate the type of bond failure, bond deflection surfaces were investigated in samples with minimum and maximum shear strength. Figure 11 shows the image of the electron microscope of the defective interface at a time of 30 and 120 min. Due to the dimples at the level of both joint, a soft defect has occurred. The results of the research are in good agreement with the results of studies by other researchers such as Wang and Kuba. They have been studying to joining the

stainless steel to other alloy with the process of joint the transient liquid phase [8].

Table 4. Results of shear bond strength at storage time of 30, 60, 120 and 180 min.

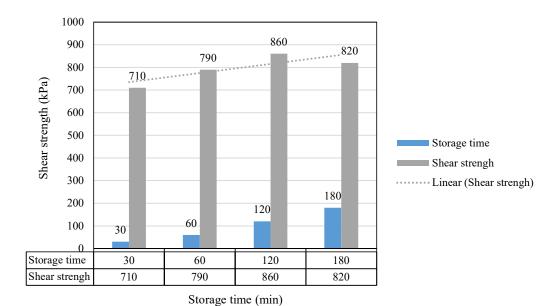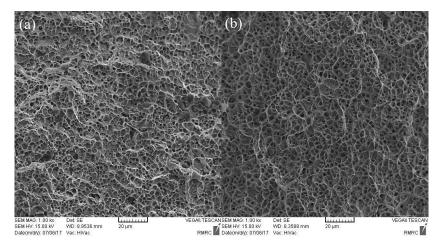| Shear strength (kPa)	Storage time(min)	Temperature (C°)
710	30	1120
790	60	1120
860	120	1120
820	180	1120

Figure 10. Statistical comparison between the obtained results of shear-strength.

Figure 11. Microscopic image of the failure levels in the shear strength of the joint in (a) storage time 120 min and (b) storage time 30 min.

4. Conclusions

The most important results from this research are as follows:

1. Suitable joint of ferritic stainless steel 430 to austenitic stainless steel304 with BNi-2 interlayer is achieved by transient liquid phase method.

2. The affected area at the joint site on the ferritic stainless steel side is larger than the austenitic steel side.

3. The average diameter of the grains increased with increasing storage time at 1120°C and the maximum grain growth time was 180 min, this growth in ferritic steel from 10 to 35 μm and in austenitic steel from 7 with 29 μm.

4. The maximum hardness of the various mashi zone, heat affected zone, base metal and interface zone, at 1120°C, it is related to 120 min of storage time due to the presence of carbide compounds and the formation of intermetallic compounds.

5. The bond strength is increased by increasing the retention time of the parts at 1120°C, which has been corrected for cutting from 710 kPa for 30 min to a maximum of 860 kPa for 120 min.

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