

Research Paper

Microstructural Evaluations of Dissimilar A335GR P22 and A312TP304H Joints Using ER-NiCr₃ Filler by GTAW

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ARTICLE INFO

Article history:

Received 7 March 2026
Revised: 21 April 2026
Accepted 14 May 2026
Available online 21 April 2025

Keywords:

A335 GR P22 steel
A312 TP 304H steel
dissimilar welding
microstructure
hardness.

ABSTRACT

In this study, dissimilar welding of H304TP312A austenitic stainless steel to 22 GR P335A low alloy steel by arc-tungsten-gas method was investigated. ER-NiCr₃ filler metal was selected and used for the above joint. The sound dissimilar welding of A312 TP 304H steel and A335 GR P22 steels were obtained by applying voltage in the range of 14-12 volts, amperage of 70-100 A and welding speed of 40-80 mm /min by GTAW method. According to the results solidification of weld metal in the dissimilar welding of A312 TP 304H steel and A335 GR P22 steel have primary austenite and dendritic structure, and due to the presence of carbide-forming elements in the filler metal, carbide formation is possible. The results of the hardness profile of the welded sample showed that in the base metal region of P22 steel there is the lowest hardness of about 194 Vickers and by moving towards A312 TP 304H steel, the hardness has an increasing trend and reaches 325 Vickers.

Citation: Romez Khaksari, A.; Abbasi-Baharanchi, M. (2025). Microstructural Evaluations of Dissimilar A335GR P22 and A312TP304H Joints Using ER-NiCr₃ Filler by GTAW, Journal of Advanced Materials and Processing, 13 (50), 49-58. Doi: 10.71670/jmatpro.2025.1239045

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1-Introduction

Today, in the power plant, refinery and petrochemical industries, in some processes, special piping systems are used to move specific fluids. This fluid transport system must have good resistance to high heat and stresses due to fluid movement. One of these processes is used in the piping system of petrochemical industry reformers. Stainless steels are often used in the design of these systems. Stainless steels contain 10 to 12% chromium, which is widely used in corrosion-resistant applications in corrosive environments as well as at high temperatures [1-6]. Group 300 alloys are the most widely used group of this type of steel. In the design of pipelines, low chromium-molybdenum alloy steels are used instead of austenitic stainless steels, which have good corrosion resistance and do not lose their strength even at high temperatures. Under such conditions, the issue of dissimilar welding between two austenitic stainless steel alloys and chromium-molybdenum low alloy steel is often raised. Chromium-molybdenum steels show good resistance at high temperatures [7-14]. The presence of chromium and molybdenum increases corrosion and heat resistance, respectively. Among the dissimilar joints of these steels, dissimilar welding of austenitic stainless steel A312TP304H (seamless pipe) and low-alloy chrome-molybdenum steel A335GR P22 (seamless pipe) are widely used in petrochemical reformer piping systems. The most important issue in welding dissimilar metals is choosing the right filler metal [15-19]. According to studies on dissimilar joints in austenitic stainless steels and low carbon steels of chromium molybdenum nickel-based metal filler ER-NiCr₃, which has good flexibility, is an option that will be evaluated in recent study.

King et al. [20] studied the failure of a joint between 2.25Cr-1Mo steel and austenitic 321 stainless steel using inconel 182 filler metal. According to the results, after heating this joint at high temperatures for 10-15 years, the heat-affected area, includes ferrite grains, and grew and cracking occurred in the same area. In 2011, Arivagegan et al. [21] investigated the dissimilar welding of 304 stainless steel and 4140 low alloy steel by different welding methods. According to the results, the melting zones are completely different from each other, and this difference is attributed to the different heat inputs and cooling rates. The results of XRD analysis of the joints showed the presence of intermetallic compounds and carbides. Hani et al. [22] investigated the failure of welding joints between carbon steel pipes and elongated stainless steel 304 containing gas in a petrochemical unit. The analysis showed that the cracks formed at the interface between the carbon steel pipe and the stainless steel weld. The

microhardness results showed the hardness of a narrow region between the weld of stainless steel and carbon steel of about 60 Rockwell, which could be due to the formation of martensite due to separation at the weld temperature and subsequent rapid cooling. The ferrite zone is adjacent to carbon steel and welded decorborate and lacks perlite, which is associated with carbon infiltration. In 2013, Pourali-Akbar et al. [23] investigated the dissimilar welding of 304 stainless steel and 45 CK carbon steel with the point on mechanical properties of the weld before and after heat treatment after welding. According to the results, the structure of the weld metal is completely austenitic, while the microstructure in the joint area consisted of two austenite-ferrite phases, which led to the skeletal morphology of δ ferrite. The presence of a δ ferrite structure leads to a decrease in ductility and toughness. Ferrite-austenite boundaries can also be potential sites for the deposition of $M_{23}C_6$ type carbides and the sigma phase (Fe-Ni-Cr-Mo tetragonal phase) [24,25]. Also Other researchers [26,27] studied the microstructure and mechanical properties of dissimilar welds of 347 stainless steel and 335 low alloy steel using tungsten gas arc welding. In this regard, two filler metals including L309ER- and ER-NiCr were used. According to the solidification results, ER-NiCr3 welding metal is similar to primary austenite and has a two-phase structure containing dendritic and interdendritic regions. NbC is a complex sediment and carbide found in the interdendritic region. The results showed that the microstructure of L309ER-weld metal includes primary ferrite with some austenite at the end of solidification, which includes skeletal ferrite. Carbon migration from the HAZ region to the smelting zone occurs at the interface between A335 low-alloy steel and L309ER filler metal. A small martensitic region with high hardness was also created at the fusion boundary, which was not observed in ER-NiCr3 metal.

Studies show that despite the importance and widespread use of the A335GR P22 and A312TP304H, there is little information about their dissimilar joint, so In this study, Microstructural Evaluations of Dissimilar A335GR P22 and A312TP304H Joints Using ER-NiCr₃ Filler by GTAW was investigated.

2-Materials and Methods

In this research, austenitic stainless steel pipe A312 TP 304H and low alloy steel cream-molybdenum A335 GR P22 have been used as the base metal. The chemical compositions of the base metals are presented in Tables 1 and 2. To weld the mentioned metals, ER-CrNi3 filler metal was used according to the chemical composition of Table 3.

Table 1. Chemical analysis of A312 TP 304H steel

Grade	UNS	Carbon	Mn	P	S	Si	Cr	Ni
TP304H	S30409	0.04-0.1	2	0.045	0.03	1	18-22	8-11

Table 2. Chemical analysis of SA335 GR P22 steel

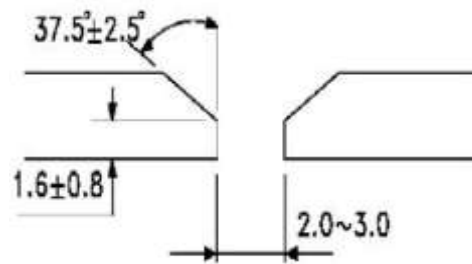
Grade	UNS	C	Mn	P	S	Si	Cr	Mo
P22	K21590	0.05-0.15	0.3-0.6	0.025	0.025	0.5	1.90-2.60	0.05-0.3

Table 3. Chemical analysis of ER-CrNi3 filler metal.

AWS	UNS	C	Mn	Fe	P	S	Si	Cu	Ni	Co	Al	Ti	Cr	Ta	Mo	V	W	Other
ER-NiCr 3	N06082	0.1	2.5 to 3.5	3	0.03	0.015	0.5	0.5	67 min	(e)	---	0.75	18 to 22	2 to 3	---	--	--	0.5

To make the weld between the base metals, 6-inch pipes with a thickness of 7.11 mm and a length of 15 cm were prepared separately. For this purpose, A312TP 304H austenitic stainless steel pipes and

low-alloy steel cream-molybdenum A335GR P22 were prepared according to ASME Sec IX standard with butt joint and V-shaped groove.

**Fig. 1.** Weld design.

The welding of the samples was carried out by arc-tungsten-gas welding method according to the prepared welding instructions. According to ASME ANSI B 31.3 standard, part A335 GR P22 was

preheated according to the thickness of the pipe before starting welding at 150 ° C by the elements. The detailed parameters of GTAW is presented in table 4.

Table 4. Welding parameters

Filler diameter	Tungsten diameter	Applied gas pressure	Shielding gas composition	Electrode polarity
2 mm	2.4 mm	8-12 Lit/min	99.99 Ar	DCEN
	Welding condition	Welding speed	Current range	Voltage range
	6 G	40-80 mm/min	70-100 A	12-14 V

Argon gas was used inside the pipe to prevent oxidation of the inner surface of the weld. Welding was done manually in 6 G position with polarity (DCEN) and in 5 passes with ER-NiCr₃ filler metal with a thickness of 2 mm. Consumable tungsten electrode containing 2% thorium with a diameter of 2.4 mm was used. To study the microstructure of base metals and the welded specimen, the specimens were first sanded using a sandpaper with a roughness of 220 to 3,000 and then polished, and then images were

prepared by light microscopy at various magnifications. Marble solution was used as etching solution to detect the microstructure of the samples. After welding and eye inspection, radiographic examination was performed according to ASME sec V standard to ensure the absence of internal defects in the welding specimen (6-inch tube). Microhardness was investigated by KOOPA machine at intervals of 1 mm.

3-Results and Discussions

Figure 2 shows the microstructure of the base metal A335 GR P22 containing ferrite grains and perlite areas. The microscopic structure of the ER-NiCr3 weld metal is also shown in Figure 3. Solidification

of ER-NiCr₃ weld metal is in the form of primary austenite and it shows a two-phase structure including dendrites and inter-dendritic areas. Carbide formation is also possible due to the presence of carbide-forming elements in the weld metal composition.

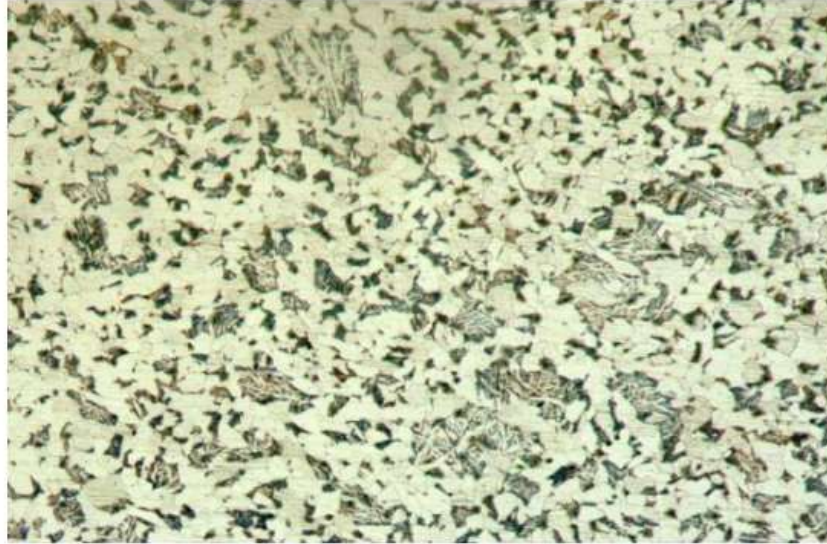


Fig. 2. Microstructure image of A335 GR P22 sample containing ferrite and perlite areas with 10x magnification.

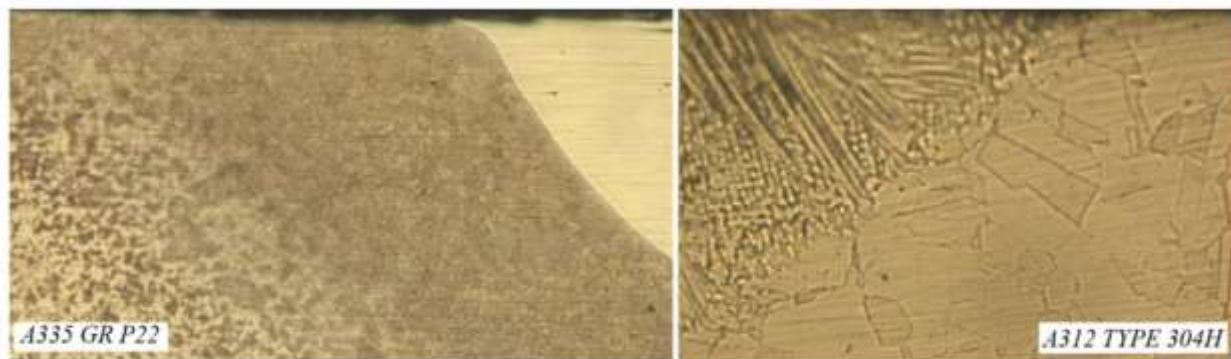


Fig. 3. Different dissimilar weld areas of A312 TYPE 304H sample and A335 GR P22 sample.

Figure 3 shows the interface between the austenitic stainless steel base metal of sample A312 TP 304H and the ER-NiCr3 weld metal, in which a completely continuous joint is observed throughout the weld. Figure 3 shows the common chapter of the low alloy steel base metal of the sample A335 GR P22 and the

weld metal ER-NiCr₃. Grain coarsening can be seen in HAZ of low alloy steel sample A335 GR P22. Figures 4 to 6 show the SEM images related to the interface between the base metals and the ER-NiCr3 weld metal, as well as the solidification of the weld metal as primary austenite and a two-phase structure including dendrites and inter-dendritic areas.

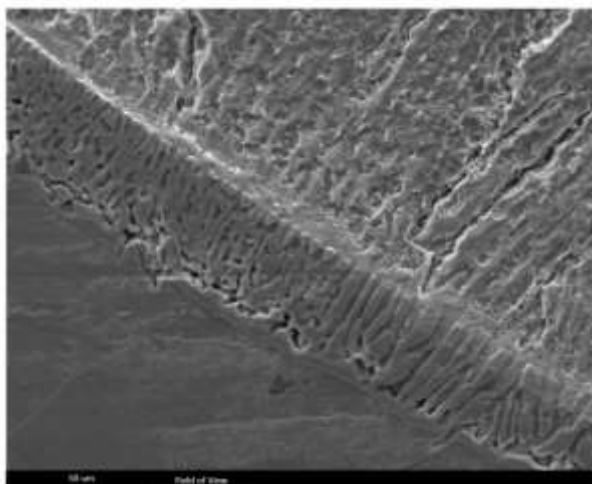


Fig. 4. SEM image related to the interface between A312 TYPE 304H base metal and ER-NiCr3 weld metal.

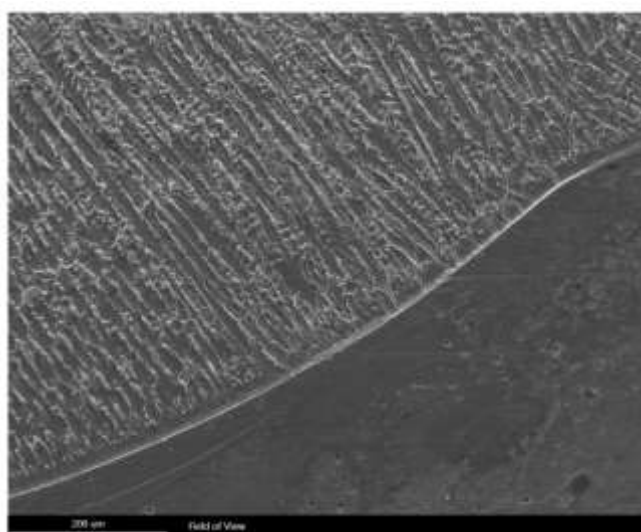


Fig. 5. SEM image of the base metal A335 GR P22 and ER-NiCr3 weld metal.

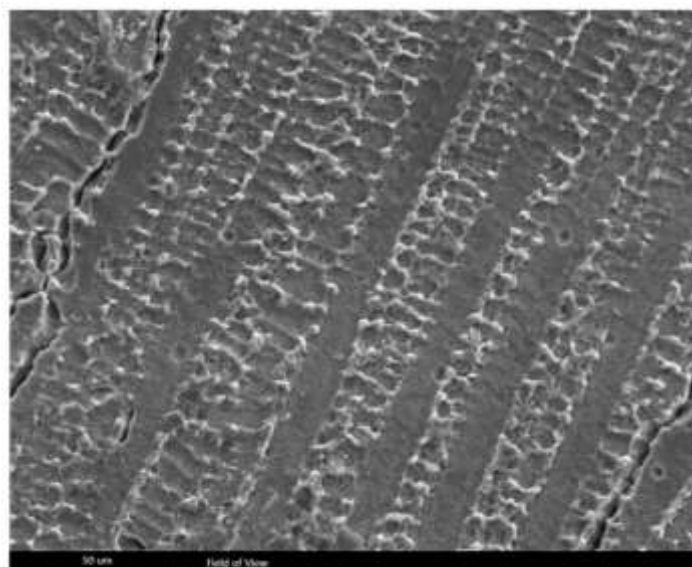


Fig. 6. SEM image of ER-NiCr₃ weld metal solidification as primary austenite and biphasic structure including dendrites and inter-dendritic areas.

Also, in Figures 7 and 8, linear changes of structural elements related to the metal base of A335 GR P22 and ER-NiCr3 weld metal and also related to the joint interface of A312 TYPE 304H base metal and ER-NiCr3 weld metal are presented. A closer look at the microstructure of the weld metal by scanning

electron microscopy showed that carbide was formed due to the presence of carbidizing elements in the weld metal composition. Also in point analysis of EDS, these carbides were identified as titanium and niobium carbides.

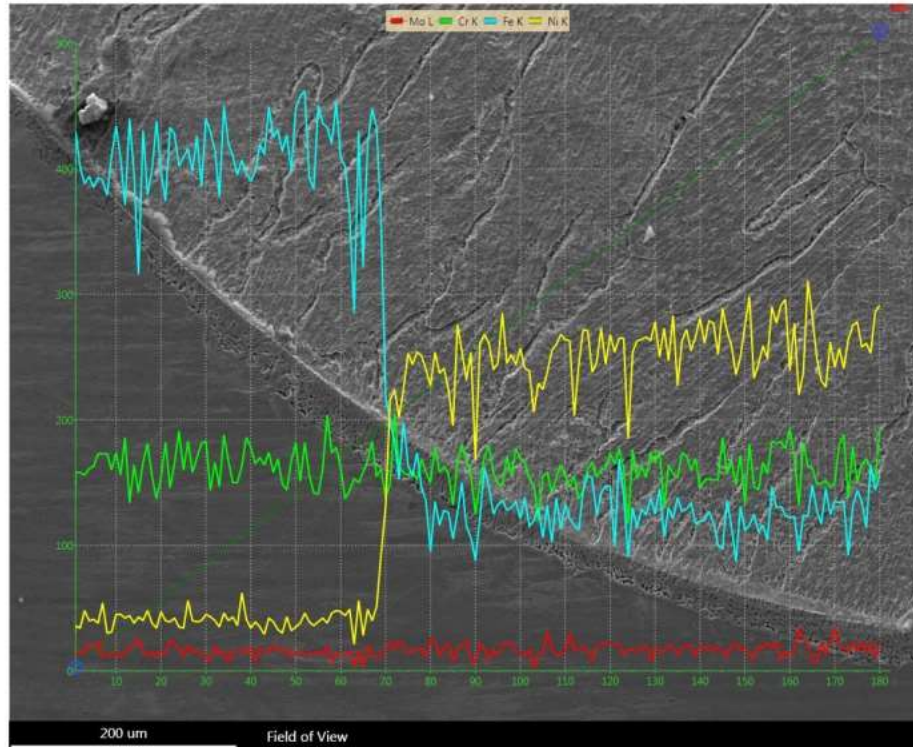


Fig. 7. Linear analysis of elements related to the interface between A312 TYPE 304H base metal and ER-NiCr₃ weld metal.

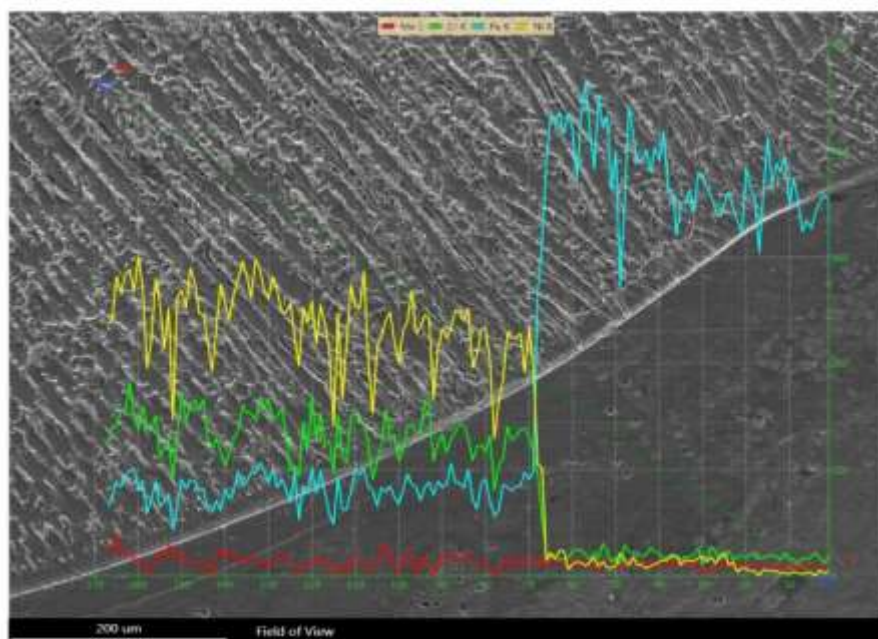


Fig. 8. Linear analysis of elements related to the interface between A335 GR P22 base metal and ER-NiCr₃ weld metal.

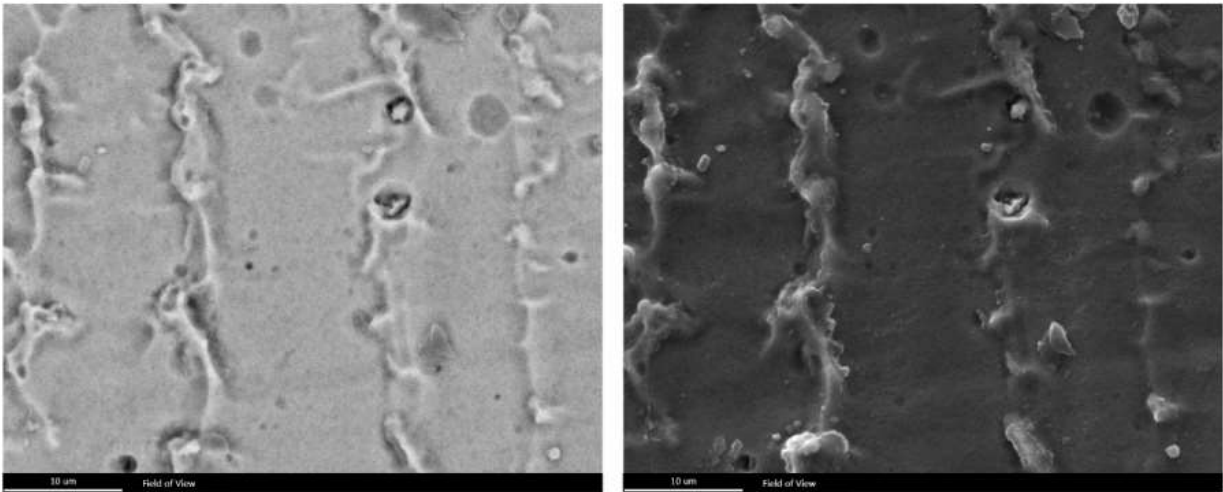


Fig. 9. SEM image related to the presence of carbide particles in the ER-NiCr₃ weld metal between dendritic areas.

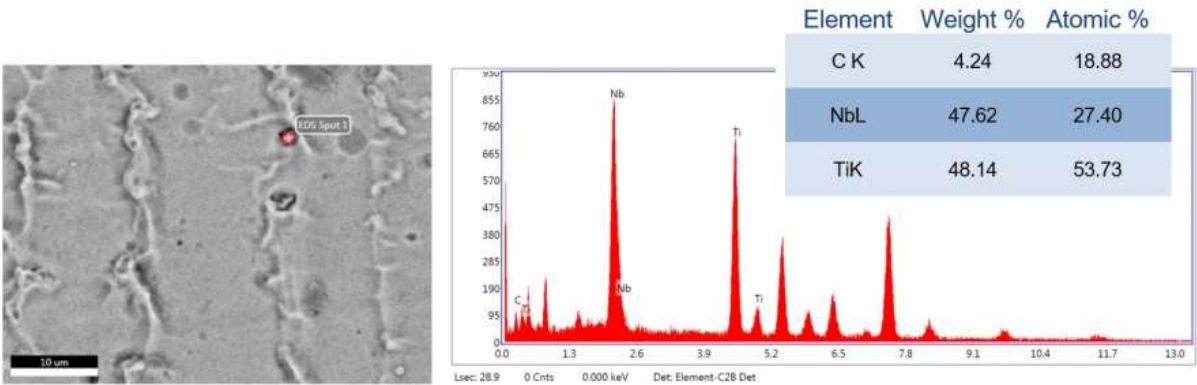


Fig. 10. EDS analysis of carbide particles in ER-NiCr₃ weld metal.

Like similar metal welding, radiography can be used to test non-destructive dissimilar welds, provided that parameters such as irradiation time and film density and radiation strength are calculated for different materials with different densities. Therefore, in this study, after welding and eye inspection, to ensure the

absence of internal defects of the welding specimen (6-inch tube) before mechanical tests, radiographic examination was performed according to ASME sec V standard. As shown in Figure 11, no significant defects can be detected.

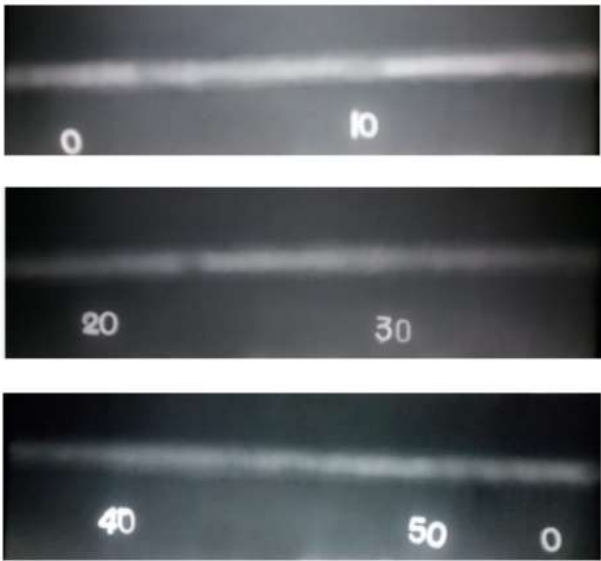


Fig. 11. Radiographic images of a 6-inch tube after welding.

The microhardness of A335 GR P22 and A312 TP 304H were measured at 265 and 351 Vickers, respectively. Figure 12 shows the weld cross-sectional hardness profiles of the ER-NiCr₃ filler metal welded specimen. Higher hardness was observed in the base metal of sample A312 TP 304H, which is due to the lack of heat to this area and the absence of sediments at the grain boundary. Reaching the HAZ area, a decrease in hardness was observed, which is due to the coarseness of the grains in the area affected by heat. An increase in hardness was observed with movement towards the weld metal. The presence of intermetallic phases and carbides of existing elements, due to the filler metal, can cause this increase. The microstructure of the central

regions along with the area of coaxial grains and fine dendritic sediments can increase the hardness in the weld center. Passing through the base metal of low alloy steel, a hardness drop was observed towards HAZ due to the coarsening of the grains in this region and also due to the infiltration of carbon from the base metal to the weld metal and therefore the increase in low carbon ferrite in the heat affected zone area, which again increases with hardness when it reaches the weld metal. It should be noted that in the welding of chromium-molybdenum steels, the hardness drop due to the welding inlet heat may be due to changes in the martensite phase, scale enlargement, recovery phenomenon, or sub-grain size.

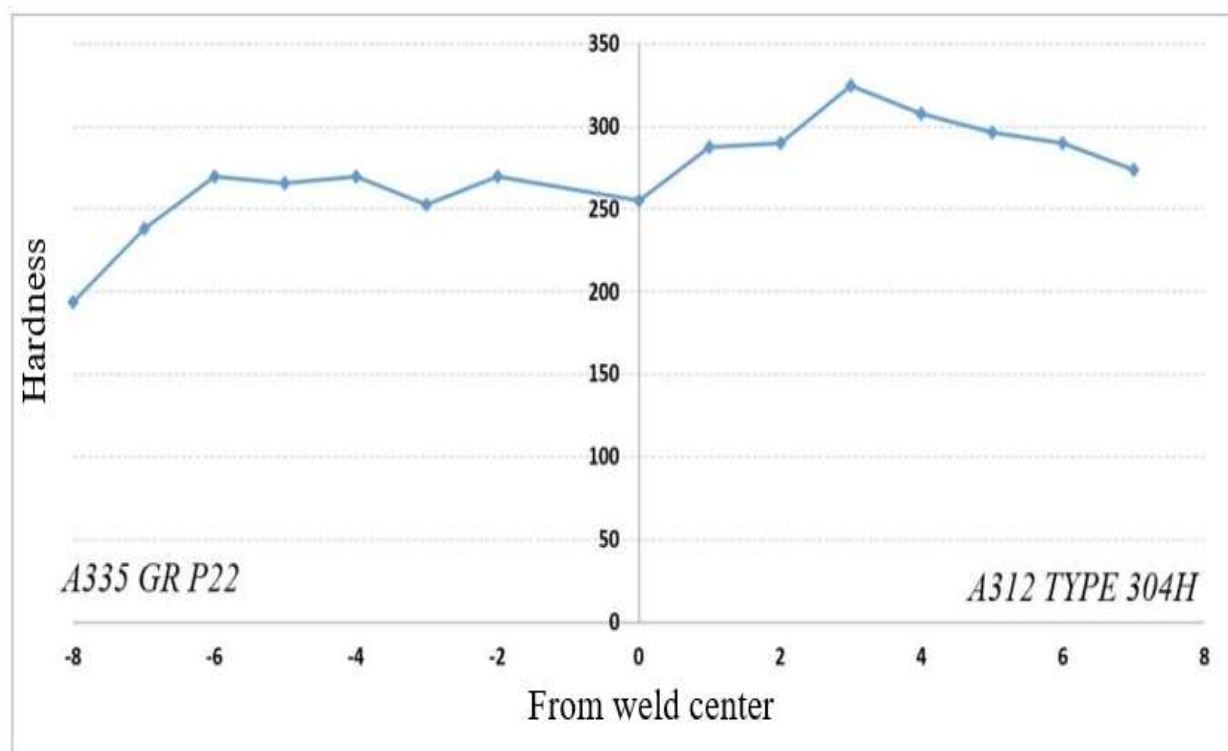


Fig. 12. Weld specimen hardness profile

4-Conclusion

In the present study, dissimilar welding between A335 GR P22 low-alloy steel and A312 TP304H austenitic stainless steel was successfully carried out using the GTAW process with ER-NiCr₃ filler metal. Sound weld joints with acceptable quality were obtained under the selected welding parameters, and radiographic examination confirmed the absence of significant internal defects in the welded samples. The results demonstrated that the ER-NiCr₃ filler metal provided good metallurgical compatibility between the two dissimilar base metals.

Microstructural investigations revealed that the weld metal solidified primarily as austenite with a dendritic and interdendritic morphology. A continuous and defect-free interface was observed between the weld metal and both base metals. Grain coarsening was detected in the heat affected zone of A335 GR P22 steel due to the thermal cycle imposed during welding. SEM observations together with EDS analysis confirmed the formation of carbide precipitates in the interdendritic regions of the weld metal, mainly consisting of titanium and niobium carbides formed by the presence of carbide-forming elements in the ER-NiCr₃ filler composition.

The hardness profile across the welded joint showed considerable variation in different regions of the weldment. The lowest hardness values were observed in the P22 steel and its heat affected zone due to grain growth and carbon migration effects, while higher hardness values were measured in the weld metal and TP304H stainless steel side because of dendritic solidification and the presence of carbide and intermetallic phases. Overall, the obtained results indicate that ER-NiCr3 filler metal is a suitable choice for dissimilar welding of A335 GR P22 and A312 TP304H steels and can provide acceptable microstructural and mechanical properties for high-temperature service applications in petrochemical and refinery industries.

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