Analysis of Dissimilar Metal Welds: X3CRNIMO.13-4 (1.4313) & CarbonSteel S355J2+N

M. N. Kyalo and J. K. Kimotho

Abstract—In manufacturing, many applications require welding of dissimilar materials. Stainless steel and carbon steel are often welded together in applications such as nuclear, hydro power, chemical, and petrochemical plants. Sufficient data on welding of such dissimilar materials may not be available or may insufficient. Samples ofX3CrNiMo.13-4 stainless steel and S355J2+N carbon steel used by Heavy Engineering Ltd Companyin hydro power project were used in this study. The samples were welded as per their procedures at specified voltages and feed speeds. The as received samples were sectioned and prepared for optical and microstructural analysis.Tensile, impact and hardnesstests were carried out to evaluate mechanical properties of the samples. After microstructural analysis, the thermally unaffected base material, S355J2+N carbon steel showed ferritic-perlite structure and the base material X3CrNiMo.13-4 stainless steel showed a martensitic structure. In the heat affected zone (HAZ) on the stainless steel side, the grain structure was observed to havetransformed and there was complete fusion. In the HAZ on the CS side, the grain structure of the weld penetrates the CS side in the shape of dendrites. During tensile testing failure occurred on the, S355J2+N base material implying that the welding method adopted was satisfactory. The highest hardness value (200 HB) was obtained on the weld area.

Keywords: Welding, dissimilar metals, Heat affected Zone (HAZ), Microstructure

I. INTRODUCTION

Joining of dissimilar metals has found wide in power generation, electronic, nuclear reactors, petrochemical and chemical industries mainly to get ideal properties in a component and enhance functional requirements [1]–[4]. However, efficient welding of dissimilar metals has posed a major challenge due to difference in thermo-mechanical and chemical properties of the materials to be joined under a common welding condition[5]. A range of problems come up in dissimilar welding like cracking, large weld residual stresses, migration of atoms during welding causing stress concentration on one side of the weld, compressive and tensile thermal stresses, stress corrosion cracking [6].

There are several techniques that are used for joining of dissimilar materials in industrial applications [7]. The mainmethods are broadly classified into three groups namely; fusion welds, low dilution welds and non-fusion welds [6].

The processes for fusion welds include shielded metal arc (SMAW), gas metal arc (GMAW), sub-merged arc (SAW), flux cored arc (FCAW), and gas tungsten arc (GTAW). Low-dilution welds include electron beam, laser, and pulsed arc; the amount of base metal melted is relatively small, and filler metals are not normally added[7]. Typical non-fusion joining processes are friction welding, and explosion welding, diffusion bonding along with brazing and soldering.

Low dilution and non-fusion methods involve expensive equipment and complex welding procedures[8]. Fusion welding is one of the most frequently used methods for joining metals[9]. Despite the difficulties associated with fusion welding, continuous efforts are being made to apply this method to the welding of dissimilar metal combinations[6]. In fusion welding, the weld metal is a mixture of the two metals being joined and the filler metal. Weld properties and composition can be determined and reasonably predicted by sampling regions in the weld bead. While the bulk of the weld is well mixed, there is an unmixed zone at the weld interface, which is a very narrow boundary layer of melted base metal that froze before mixing with the weld metal[10]. There is also a zone of un-melted base metal that will have been altered by the heat of welding referred to as the heat affected zone.

Locally, thereis high demand in quality of works which calls for microstructural analysis with chemical profiling of the weld region and analysis of mechanical properties. There is limited competence for such analysis in local institutions. In this work, dissimilar metal shielded arc metal welding of 20mm thick X3CrNiMo.13-4 steel and S355J2+N steel plates has been attempted with selected filler rods. The dissimilar steel weld joints were characterized in regard to metallurgical and mechanical properties in as-welded and post weld heat treated conditions.

II. EXPERIMENTAL PROCEDURE

The materials investigated are X3CrNiMo.13-4Stainless steel and S355J2+N carbon steel plates with thickness of 20mm.X3CrNiMo.3-4 is chromium nickel martensitic stainless steel with molybdenum addition. S355J2+N is a low carbon steel structural steel with J2 denoting Charpy impact tests at –

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20°C and N denoting supply condition normalized or normalized rolled.Table 1 and **Error! Reference source not found.**show chemical composition of the materials.

Table 1: Percentage Chemical composition of Base Metals

Element	X3CrNiMo.13-4	S355J2+N steel
C	0.16	0.022
Si	0.23	0.51
Mn	1.55	0.62
P	0.025	0.015
S	0.004	0.004
N	0.006	0.0223
Cr	0.03	12.74
Ni	0.05	3.66
Mo	0.01	0.54
V	0.01	-
Al	0.38	-
Cu	0.03	-

Similar and dissimilar metal combinations were welded through shielded metal arc welding technique. The weld was double-sided V-groove with full penetration. The dimensions of the grooves were; bevel angle of $45^0$and a root gap of 5 mm. welding was done with multiple passes according to ASME standards by qualified welders.Samples were coded according to Samples RUS-4 and RUS-5 were welded with welding rods designated ISO 3581 of dimensions 3.2X 350mm. The chemical composition of the weld rods is presented in
Table 3.

Table 2: Welding joints codes used

Sample Code	Weld joint
RUS-4	X3CrNiMo.13-4 & S355J2+N
RUS-5	X3CrNiMo.13-4 & X3CrNiMo.13-4
RUS-6	S355J2+N& S355J2+N

Table 3: Filler material chemical composition

Element	RUS-4	RUS-5	RUS-5
C	0.09	0.03	0.04
Si	0.75	0.36	0.42
Mn	6.31	0.60	1.40
P	0.016	0.021	0.014
S	0.004	0.006	0.009
Cr	18.85	12.22	12.22
Mo	0.02	0.57	0.57
Ni	8.53	4.81	0.40

A conventional heat treatment cycle was adopted to cool the joint to below 100°C to ensure full transformation of the weld and HAZ to martensite, followed by closely controlled heating to minimize stresses from temperature variations, PWHT at around 700°C for two hours then controlled cooling to ambient temperature. Sections of each sample were mechanically cut to include the heat affected zones of both sides of the weld and the weld metal itself. The specimens for metallographic studies were prepared by following a standard procedure which involved sectioning, grinding and polishing with emery papers of up to 2000 grit size followed by cloth polishing with alumina powder. After that the specimens RUS-4 and RUS-6 were etched with Nital, 2% HNO_3 in alcohol to reveal the microstructure on the low alloyed steel side and the microstructure on the low alloyed steel side is evaluated. Finally Carpenter 300 Series was used to reveal the microstructure in the weld and on the stainless steel on samples RUS-4 and RUS-5. The weldments microstructures were studied by metallography on various regions using Olympus optical microscope (Model: BX41M-LED, Camera: Sc50, Software: Stream Essentials).

Table 4: Mechanical properties of base materials

Property	X3CrNiMo.13-4	S355 J2+N
Hardness (HB)	320	180
Yield strength N/mm2	630 min	315-355
Tensile strength N/mm2	780-980	490-630
Elongation	15-19.4	18-20
Hardness (HB)	269-275	146-187

To ensure that the weld metal is not weaker than the rest of the material, three tensile tests for each sample were carried out. Tensile testing to ensure that the weld metal not is weaker than the rest of the materials tensile testing was made, three tests for each sample. The specimen werecut transversely from the weld joint so that the weld axis remains in the middle of the parallel length of the specimen. Tensile tests on welded specimens were performed according to ASME standard SEC IX, QW-462(a)' Sample lengths were 300mm, width 19mm and thickness 19mm. A simple and economical way to characterize the mechanical properties and microstructure is by performing hardness measurements. By performing hardness tests, the highest and lowest levels of hardness could be determined. The area of interest was the transition from parent metal to weld metal takes place and in the root bead of the weld. A cross-section from each sample was taken transverse the weld by mechanical cutting. After the samples were cut they wereground and polished in order to make obtain a smooth surface. The hardness indentations were performed in rows at three different positions of the weld; the root bead, the first weld bead and the top weld. The samples were tested with HV1.5, HV 1.5 meaning that 1.5 kg load is applied during the hardness measurement.

III. RESULTS AND DISCUSSION

A.Microstructural tests

Figure 1 shows microstructure of base materials S355J2+N carbon steel shows a ferritic-perlite structure and the base material X3CrNiMo.13-4 stainless steel shows a martensitic structure.

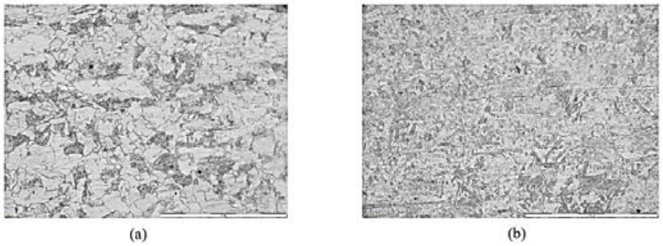

Figure 1: Micrographs of base materials (a) S355J2+N, (b) X3CrNiMo.13-4 (X500)

Figure 2shows micrographs of RUS-4 weld joint micrographs between X3CrNiMo.13-4 and S355J2+N. In the heat affected zone (HAZ) on the SS side, the size of the grain structure is observed to have transformed and there is complete fusion. The predominant phase transformation in the martensitic stainless steel welds is the austenite to martensite transformation that occurs in the fusion zone and regions of the HAZ that have been heated into the austenite phase field [11]. In the heat affected zone (HAZ) on the S355J2+N side, the grain structure of the weld penetrates the S355J2+N side in the shape of dendrites. The dendritic structure are formed in the partially melted zone just after the fusion line. Inside the structure of the weld metal sporadic inclusions were found and assumed to be carbides due to possible precipitation of carbon.

Figure 3(a) shows micrographs of RUS-5 joint with only X3CrNiMo.13-4 materials. The base material X3CrNiMo.13-4 stainless steel side shows a martensitic structure. In the heat affected zone (HAZ) the size of the grain structures is observed to have increased and complete fusion is observed, the weld region shows a martensitic structure with a texture variation from the base material. Inside the weld we found sporadic inclusions that are assumed to be carbides.

Micrograph of sample RUS-6 of the base metal shows ferrite-pearlite microstructure appearing to be equiaxed as shown in Figure 3(b). shows a micrograph of the weld interface. Complete fusion is observed with coarsened grains in the affected zone (HAZ). The weld region shows a non equiaxed grain structure (Figure: RUS-06-Weld X500).

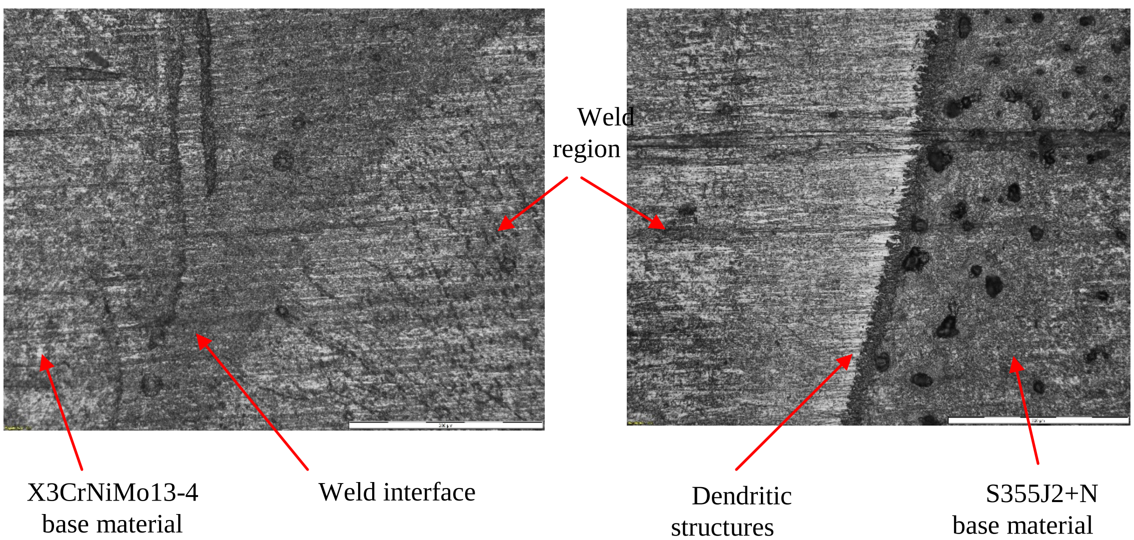

Figure 2: RUS-04 Weld jointmicrographs between X3CrNiMo.13-4and S355J2+N(X200)

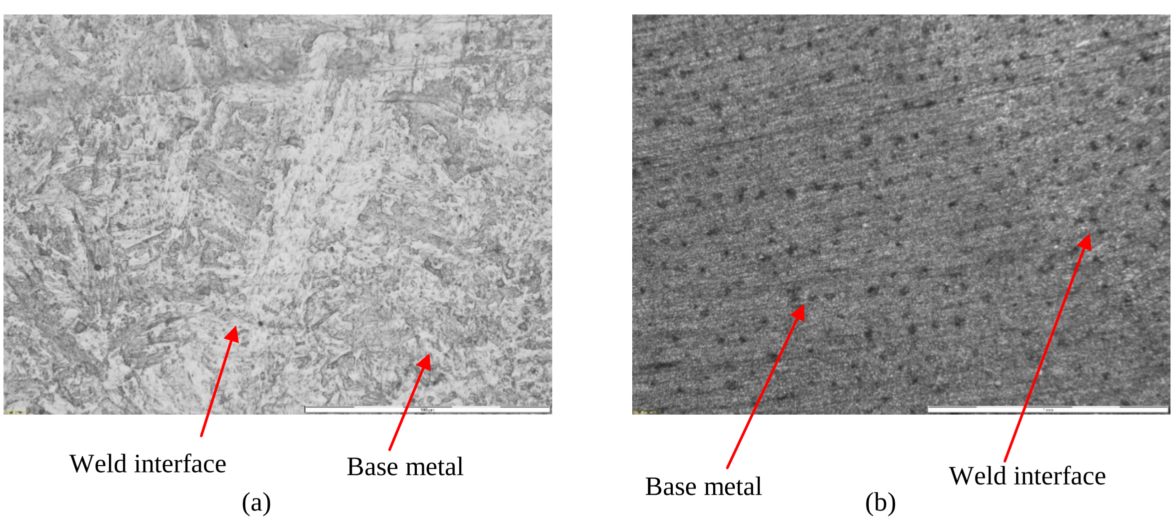

Figure 3: (a) RUS-05 Weld joint micrographs with only X3CrNiMo.13-4(X500); (b) RUS-06 Weld joint micrographs with only S355J2+N (X50)

B.Tensile tests

The mechanical properties of the welded joint are presented Table 5.The as-welded specimen and post weld heat treated (PWHT) tensile test specimens failed from the S355J2+N steel base metal which suggests that weld joint is stronger than the S355J2+N steel base metal. PWHT reduced tensile strength of the joint coupled with a slight increase in ductility due to the tempering of the base metal. In RUS-6 samples, fracture took place at S355J2+N steel base metal far away from the S355J2+N steel-weld zone interface.

Table 5: Mechanical properties of the weld joint in as-welded and PWHT condition. Mechanical Property

Mechanical property	RUS-4	RUS-5	RUS-6
Yield strength (0.2% offset)	476	890	370
UTS (MPa)	470-620	780-958	470-597

C.Hardness tests

Hardness value of the as-received X3CrNiMo.13-4base steel was measured as 284HB and 171HB for S355J2+N. For joint RUS-4, a hardness value of 200HB obtained on the weld lower than that of X3CrNiMo.13-4 base and higher than value on S355J2+N base. This could have been caused by diffusion of elements during elements and transformation of microstructure. The highest hardness was obtained weld area RUS-5. The high value was caused by formation of martensitic structure with limited diffusion of elements since the filler material chemical compositionwas similar to the base material properties.

Table 6: Measured hardness of specimens

Description	Vickers Hardness (HV)	Brinell Hardness (HB)
Base metal 1.4313 X3CrNiMo 13-4	300	284
Base metal S355J2+N	180	171
Weld Area S355J2+N & X3CrNiMo 13-4	210	200
Weld Area X3CrNiMo 13-4	310	294

IV. CONCLUSION

This work has investigated the dissimilar welding of X3CrNiMo.13-4 and S355J2+N steels by means of Shielded metal arc welded technique. Welded samples of similar combinations were tested for comparison purposes.Microstructural analysis show that complete fusion of welding was achieved on both sides of base material and weld. The X3CrNiMo.13-4 weld interface showed coarse martensitic structure. The weld penetrates S355J2+N base material without any visible fractures at microstructure level. Yield strength of 476MPa was achieved from tensile tests with failure occurring on the S355J2+N base material. The method and filler material adopted for the welding process is deemed satisfactory from the experimental results. Future work will include chemical profiling of the weld and heat affected zone, electron microscopy and corrosion analysis.

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