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MICROSTRUCTURE ANALYSIS OF DISSMILAR METALS WELD BETWEEN S690Q AND S355J2+N STEEL UNDER FLAME STRAIGHTENING TREATMENT

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Flame straightening process is needed to improve joint alignments due to the distortions induced by welding heat. This research shows that flame straightening can be applied safely on the weld of dissimilar metals such as S690Q and S355J2+N steel. The results indicated an increase in hardness of the flame straightened base metal, heat affected zone (HAZ), and weld metal due to pearlite transformation in these areas. Furthermore, the two metals were welded in accordance to the welding procedure standard (WPS) and then straightened by applying heat. It was then cooled rapidly with an air jet along the root of the weld joint. Lastly, microstructure investigation and hardness test were carried out on the area which was flame straightened.

Keywords: S690Q, S355J2+N, flame straightening, dissimilar metals weld, microstructure

INTRODUCTION

Welded joints of dissimilar metals are required to meet several environmental, economic, and loading conditions. These joints generate lighter, cheaper, and stronger constructions than of similar metals [1]. An example is the welding of dissimilar metals such as the S355J2+N and S690Q steels, in train bogies. The first bogie section, called Bolster, is made using S690Q high-strength steel because it acts as a support for the train's load hence it requires a very strong material. Meanwhile, the other bogie section, called the headstock assembly, does not experience high loads like the bolster hence it is only made using S355J2+N steel. These two parts, the bolster, and the headstock assembly are joined by a welding process. This dissimilar metal structure has successfully met the engineering requirements to withstand the required load and it is cost-effective compared to an all-S690Q steel structure.

Furthermore, the process of welding dissimilar metals leads to the generating of excess heat, and this results in some engineering problems. These problems arise because of the differences in the thermal, physical, metallurgical, and mechanical properties of the materials being welded. One of the most common problems is welding distortion, which is a joint misalignment caused by the different thermal expansions in the area around the weld joint of the materials to be welded. This problem causes changes in the structural dimensions of the materials in such a way that they will need to be straightened in order to achieve the required size tolerance. A very common practice for this purpose is the flame straightening process. This process is simply the application of localized heat to the weld joint area by using an oxy-acetylene torch following a predetermined pattern to control geometric distortions or tolerance deviations [2].

Subsequently, flame straightening for similar metals has been extensively studied by previous researchers [2-4], but that of dissimilar metals weld, especially S355J2+N and S690Q steel, is still limited. In this research, the effects of the flame straightening process on the hardness of dissimilar metals weld were evaluated. The dissimilar metals, S355J2+N and S690Q steel were welded using Gas Metal Arc with a single V groove multi-pass butt joint and then the joint was flame straightened.

EXPERIMENTAL PROCEDURES

The base metals used were S355J2+N and S690Q steel plates with dimensions of 400 x 150 x 25 mm while the filler metal was AWS ER 70S-6. The chemical composition of those materials is shown in Table 1. Furthermore, the base metals were welded using a Gas Metal Arc Welding with the joint configuration, as shown in Figure 1, in accordance with the certified and approved Welding Specification Procedure, which is depicted in Tables 2 and 3.

After the welding process was complete, the weld joint was then flame straightened according to the manual book from Linde Group [5]. The process was conducted with a natural flame of oxy-acetylene gas at a temperature of 600-650 ºC and a torch with a diameter of 30-50 mm as shown

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Table 1 **Chemical composition of materials /wt.%**

Element	Materials		
	S355J2+N	S690Q	ER70S-6
P	0,005	0,019	0,025
C	0,15	0,21	0,15
S	0,001	0,046	0,035
Mn	1,42	1,46	1,85
Cu	0,01	0,17	0,85
Si	0,4	0,42	1,15
Cr	0,02	0,09	<0,5
Mo	0,002	-	<0,5
Nb	0,029	-	-
Ni	0,16	0,04	<0,5
Ti	0,003	-	-
V	0,058	-	-
Fe	Bal.	Bal.	Bal.

in Figure 2. Furthermore, the flame straightening process was carried out along the weld root by moving the flame torch reciprocally at a speed of 10 cm/minute until it reached the desired temperature and then was cooled off using jet air. The microstructure and hardness of the weld specimens with flame straightening were also investigated. For the sake of comparison, similar tests were carried out on the welding specimens without flame straightening.

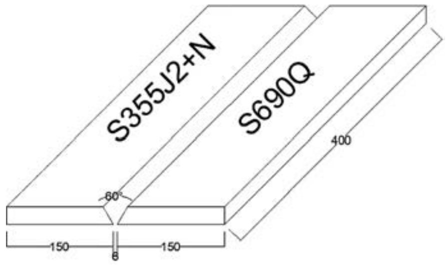

Figure 1 Weld joint configuration

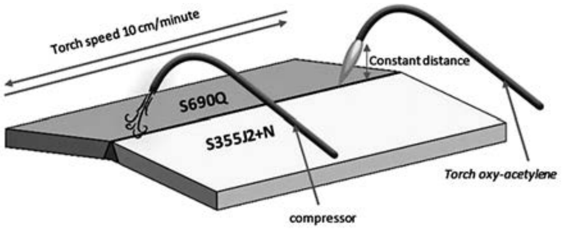

Figure 2 Flame straightening process

Table 2 **Welding parameters**

Welding Process	Semiautomatic (GMAW) (135)
Type of Weld	Groove Weld
Pass	Multi-pass
Size of Weld	Max. 50
Position	Flat
Type of Material	All Group 1-3 (S355J2, S690Q)
Thickness of Material	12-50 mm
Filler Metal	AWS ER 70S-6 (A5.18)
Diameter of Filler	1,2 mm
Shielding Gas	Ar 82 % + CO_2 18 %
Shielding Gas Flow	15-17 l/min
Pre-Heating Temperature	100 °C
Interpass Temperature	200 °C
Metal Transfer Mode	Spray
Cleaning Method	Grinding, Brushing

Table 3 **Welding Process Detail**

Passes	1st (Root Pass)	2-N pass
Polarity	DC+	DC+
Ampere /A	200-240	240-260
Voltage /V	24-26	26-30
Wire Speed /mm/min	30-50	100-120
Travel Speed /mm/min	200-250	270-390
Heat Input /J/mm	1.872	1.733

RESULTS AND DISCUSSION

Based on the standard metallography for steel, the microstructure of the weld joint was examined through an optical microscope and was taken from the base metal (BM), heat-affected zone (HAZ), and weld metal (WM). Figures 3 and 4 show the microstructure of the weld joint without and with flame straightening respectively. The microstructure of S355J2+N consists of a combination of ferrite (bright) and pearlite (dark). In rolled steel sheets, it is common for grains in the pearlite region to be generally columnar and distributed along the rolling direction [6-8]. The amount of ferrite is approximately 80 % and the pearlite accounts for the rest [8, 9]. In addition, the microstructure of S690Q steel is a combination of tempered martensite, bainite, and ferrite. This is consistent with the quenching and tempering process used in the manufacture of this steel [10-12]. The individual crystal of martensite appears to be long and characterized as needlelike and can also be called lath martensite. The lath designation is used to describe the unit of martensite that form in low or medium carbon steel [13]. Although the maximum temperature during the flame straightening was 650 °C, there were no chances of heat spreading and inducing the modification in the phases, grain size, and grain morphology of both the S355J2+N and S690Q base metals due to the air jet's high cooling rate.

Figure 3 shows the microstructure of a weld joint without flame straightening. It can be seen from the figure that the ferrite-pearlite transformation began while the initial rolled columnar structure of the pearlite was still clearly visible. The maximum temperature in the HAZ reached recrystallization in a short time hence it was not sufficient for new crystal grains to grow and only the finer grains were formed [14,15]. When flame straightening was applied to the joint (Figure 4), the ferrite and pearlite grain sizes decreased and became finer than that of the joint without flame straightening and this was because of the second transformation of ferrite and pearlite. The HAZ microstructure of S690Q steel is classified as a partially transforming zone because the grains do not change completely. The welding heat input only makes the HAZ grain size smaller than that of the base metals. This was because the HAZ temperature reached the point of recrystallization [10]. When flame straightening was applied, the microstructure of HAZ S690Q steel was dominated by fine martensite and bainite (Figure 4).

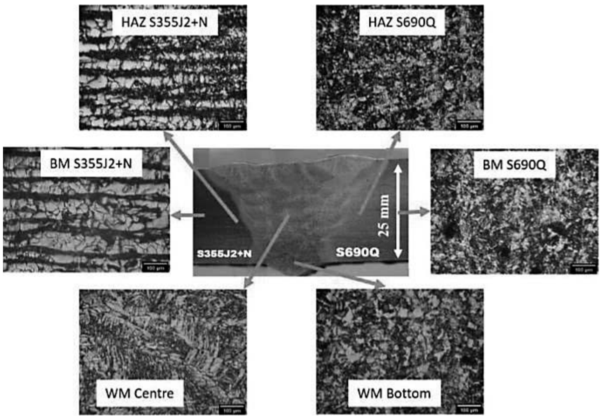

Figure 3 Impact toughness value of A36 welding plate at different cooling media.

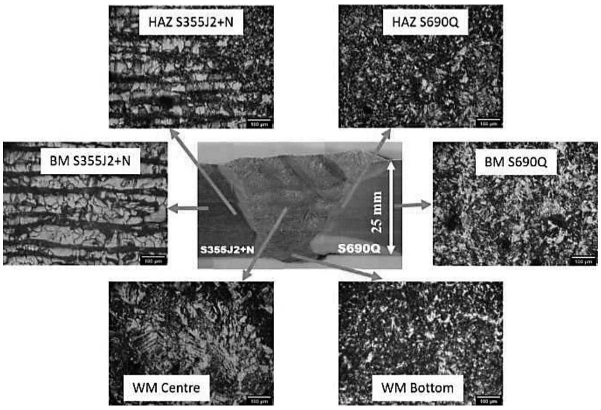

Figure 4 Microscopic photo of the fractured surface cooled through (a) air, (b) water, and (c) ice.

Additionally, the microstructure of the weld metal was examined at the center and root (bottom) lines of the weld joint to evaluate the effects of flame straightening on the metallic plate's thickness direction. The microstructure in the center line of the weld metal without and with flame straightening is shown in Figures 3 and 4 respectively. They consist of pearlite, grain boundary ferrite, widmanstatten ferrite, acicular ferrite, and polygonal ferrite. It was found that the microstructure of both specimens are similar and this means that the center line of the weld metal was not affected by the flame straightening process. This is due to the fact that the heat could not spread appropriately due to low temperature, and the quick cooling period. Furthermore, the weld metal's root microstructure consists of ferrite and pearlite. By comparing Figures 3 and 4, it is clear that the grains of the flame straightened weld metal is finer than that of the non-flame straightened weld metal. Also, the root of the weld metal experienced heating during the flame straightening process and reached the recrystallization temperature which made the grains size of the pearlite and ferrite become finer [15].

Figure 5 shows the hardness distribution of the weld joint both with and without flame straightening. The location of the hardness test was the same as that of the microstructure test. This was conducted at two different locations, which include the center line and the welded joint's root. Generally, the lowest weld hardness is located at the base metal of the S355J2+N steel. Its microstructure is mostly dominated by ferrite and a small amount of pearlite. The ferrite phase is soft and ductile, while that of pearlite is hard and brittle [8]. Furthermore, the base metal of S690Q steel is harder than that of the S355J2+N steel. The S690Q steel's microstructure is dominated by tempered martensite and bainite and both phases have high hardness [13]. The hardness of the weld metal is also higher than that of the base metal of S355J2+N steel, but lower than the base metal of S690Q steel. This is in accordance with the research conducted by Ermakova et al. [16]. Following this, the hardness increased in the HAZ of both specimens as a result of the presence of fine pearlite and ferrite grains in the S355J2+N steel and the fine martensite grains in the S690Q steel. Grain refinement can increase the strength, hardness, and toughness of the steel [8]. The difference in hardness between the flame straightened and non-flame straightened specimen at the center line of the weld metal is small and negligible and the flame straightening process did not affect this hardness. The flame straightening effect only occurred at the bottom area of the weld joint. In this area, the hardness of base metal S355J2+N was increased by approximately 29 % after straightening. This process made the ferrite grain finer, causing the amount of grain boundary to increase. In addition, the hardness of base metal S690Q also increased by about 12 % due to the increase of its martensite. Lastly, the HAZ microstructure recrystallized and the grain became finer and the smaller grain size led to an increase in the material's hardness and strength [13].

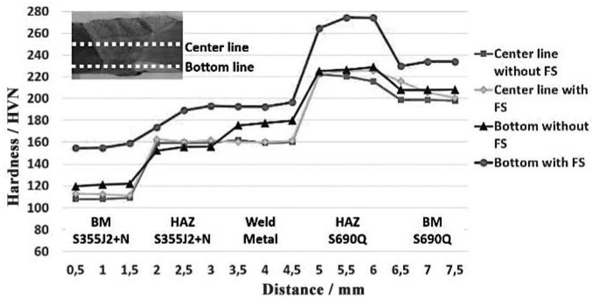

Figure 5 Hardness distribution of weld joint with and without flame straightening.

CONCLUSIONS

Based on the results, it can be concluded that:

- The flame straightening process affects both the microstructure and hardness at the root of weld joints but not at their center line and face.
- The flame straightening process increases the hardness due to the microstructure's finer grain..

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Note: The responsible English translator is the Native Proofreading Service - Indonesia.