Manufacturing Technologies and Applications
MATECA

Evaluation of Mechanical Properties of S355J2C and HBW450 Materials Joined by MAG Welding Method Using Different Welding Groove Geometries

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ABSTRACT

In this study, S355J2C and Hardox (HBW450) sheets, which are used extensively in the manufacturing sector, were joined using the robotic MAG welding method by opening the V and X weld groove. Three different variable welding speeds were used in the joints, while other welding parameters were fixed. Microstructural examinations and mechanical tests were carried out on the welded materials produced. The microstructural examinations clearly showed the transition from the base metal to the weld metal and the formation of grains with dendritic structures directed towards the weld centre. The investigations showed that there was a relationship between welding speed and heat input and that hardness and tensile values increased with increasing welding speed. In the microhardness measurements, the lowest hardness values of all the test specimens were measured from the S355J2C base material. It was found that the hardness value of the weld metal was higher than the S355J2C base material and lower than the HBW450 base material, which would be the average of the hardness values of the two materials used. In addition, in the tensile tests, all the specimens failed from the S355J2C base material. As a result of the tests carried out, it was found that the different weld groove geometries did not play a very effective role in the mechanical values of the joints or the resulting microstructure.

Keywords: *S355J2C, Hardox, HBW450, MAG welding*

Farklı Kaynak Ağzı Geometrileri Kullanılarak MAG Kaynak Yöntemiyle Birleştirilen S355J2C ve HBW450 Malzemelerin Mekanik Özelliklerinin Değerlendirilmesi

ÖZET

Bu çalışmada, imalat sektöründe yoğun olarak kullanılan S355J2C ve Hardox (HBW450) levhalar V ve X kaynak ağızları açılarak robotik MAG kaynak yöntemi kullanılarak birleştirilmiştir. Birleştirmelerde diğer kaynak parametrelerinin sabit olduğu değişken 3 farklı kaynak hızı kullanılmıştır. Üretilen kaynaklı malzemelere mikroyapı incelemeleri ve mekanik testler uygulanmıştır. Mikroyapı incelemelerinde ana metallerden kaynak metaline geçiş net olarak görülmüş ve kaynak merkezine doğru yönlenmiş dendritik yapı içeren tanelerin oluştuğu tespit edilmiştir. Yapılan incelemeler sonrasında kaynak hızı ile ısı girdisi arasında bir ilişki olduğu artan kaynak hızı ile birlikte sertlik ve çekme değerlerinin de artış gösterdiği belirlenmiştir. Mikrosertlik ölçümlerinde tüm deney numunelerinde en düşük sertlik değerleri S355J2C ana malzemeden ölçülmüştür. Kaynak metalinin sertlik değeri kullanılan her iki malzemenin sertlik değerlerinin ortalaması olacak şekilde S355J2C ana malzemeden yüksek HBW450 ana malzemeden ise düşük olduğu belirlenmiştir. Ayrıca yapılan çekme testlerinde tüm numuneler S355J2C ana malzemeden kopmuştur. Uygulanan testler sonucunda farklı kaynak ağzı geometrilerinin birleştirmelerin mekanik değerleri üzerinde veya oluşan mikroyapıda fazlaca etkin bir rol oynamadığı tespit edilmiştir.

Anahtar Kelimeler: *S355J2C, Hardox, HBW450, MAG kaynağı*

1. INTRODUCTION

Hardox steels are a type of material that is used intensively in the industry, has high strength and is resistant to wear [1-3]. Especially, it's very good wear resistance extends the life of the parts it is used in. The superior toughness and hardness values of hardox steels are due to the martensite phase they have [4]. Due to these superior properties, these materials are used in many different areas such as forestry, mining and agricultural equipment production where harsh working conditions are intense [1]. These steels show good weldability

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Received 04.07.2025; Revised 20.08.2025; Accepted 21.08.2025
https://doi.org/10.52795/mateca.1734912
To cite this article: E.A. Ayyıldız, M.S. Yıldırım, A. Durgutlu, Evaluation of Mechanical Properties of S355J2C and HBW450 Materials Joined by MAG Welding Method Using Different Welding Groove Geometries, Manufacturing Technologies and Applications 6(2) (2025) 239-247.

properties and their low carbon equivalent makes them more resistant to cracks when compared to other high-strength steels [5,6].

However, the superior properties it possesses increase the costs of hardox materials. Therefore, S355J2C materials are frequently preferred instead of hardox materials in jobs where relatively low wear and strength are required [7]. Since the carbon equivalence of these materials is low, their weldability is high. S355J2C materials are frequently used in machine manufacturing, shaft and automotive equipment production [8].

With technological developments in manufacturing processes, the need for using different material pairs together is increasing day by day [7,9]. The most frequently used joining technique in joining these material pairs is welding [10]. MAG welding is one of the most preferred welding methods in the manufacturing sector, especially because it is practical and economical, continuous welding can be done, and parameter controls are easy [10-12]. Another advantage of the MAG welding method is that it can be easily adapted to automation and robotic applications. In robotic welding applications, better weld seams are obtained due to the easy control of welding parameters compared to manual welding processes. Robotic welding processes have been frequently used in manufacturing processes in recent years due to the minimization of material and time loss caused by frequent errors in manual welding processes [9].

In this study, S355J2C and hardox (HBW450) sheets were joined using the robotic MAG welding method by opening V and X welding groove. In the joining, 3 different variable welding speeds were used, with other welding parameters being constant. Microhardness, tensile and bending tests were applied to the obtained welded joints together with microstructure examinations.

2. MATERIAL AND METHOD

In this study, 100x300 mm sized 8 mm thick S355J2C and HBW450 sheets were joined using robotic MAG welding method by opening different welding groove shapes. The aim here is to prevent access to the materials to be welded from both sides. X and V welding groove were opened on the sheets to be joined using machining methods. The chemical content of the 1.2 mm thick gas metal arc welding wire (SG2) used in the joining processes of the materials and generally preferred, and the joined materials are given in Table 1. In the welding processes, the sheets with V welding groove were joined in 2 passes as root and cover, and the sheets with X welding groove were joined in 2 passes in total, 1 on the front and back surfaces (Figure 1).

Table 1. Chemical contents of materials used in welding processes

	C	P	S	Mn	Si	Cu	Al	Cr	Ni	Mo	B
S355j2C	0,2	1,035	0,035	1,6	0,55	0,25-0,40	0,02	-	-	-	-
HBW 450	0,26	0,025	0,01	1,6	0,7	-	-	1,4	1,5	0,6	0,005
SG2	0,06	-	-	1,1	0,55	-	-	-	-	-	-

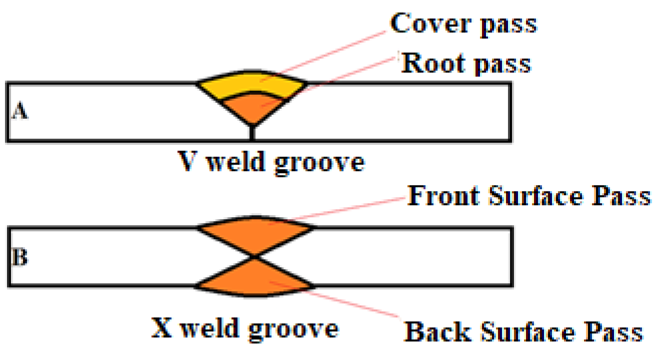

Figure 1. Schematic representation of weld groove.

Welding operations were carried out using 3 different welding speeds for each welding groove form. The welding parameters used in the experimental studies are given in Table 2 and Table 3 below. Since the amperage values in the welding machine used are determined automatically according to the welding wire speed, the welding wire speeds are given in the tables. Again, in Figure 2 below, the locations where the test samples were taken from the welded joints for examination purposes are shown.

Table 2. Welding parameters used in V-weld groove joint.

Welding Speed	**V Weld Groove**					
	Root Pass			**Cover Pass**		
	V_{wire} (cm/min)	Voltage (V)	V_{weld} (cm/min)	V_{wire} (cm/min)	Voltage (V)	V_{weld} (cm/min)
1	800	24	50	1200	28	45
2	800	24	50	1200	28	50
3	800	24	50	1200	28	55

Table 3. Welding parameters used in the X weld groove joint.

Welding Speed	**X Weld Groove**					
	Front Surface Pass			**Back Surface Pass**		
	V_{wire} (cm/min)	Voltage (V)	V_{weld} (cm/min)	V_{wire} (cm/min)	Voltage (V)	V_{weld} (cm/min)
1	800	25	45	800	25	45
2	800	25	50	800	25	50
3	800	25	55	800	25	55

Samples prepared for microstructure examination of the joint areas of the samples where welded joints were performed were subjected to standard metallographic processes and made ready for image acquisition. Afterwards, these prepared samples were etched using 2% Nital solution. Images were taken from the samples prepared for imaging using a Leica DM4000M optical microscope. Microhardness measurements of the welded samples were performed using a Quness 30M model device using a Vickers hardness measurement method using a 0,5 kg load. Tensile strength measurements of the welded samples were performed using Instron 3369 tensile testing device with samples prepared in accordance with ASTM E8-M standard.

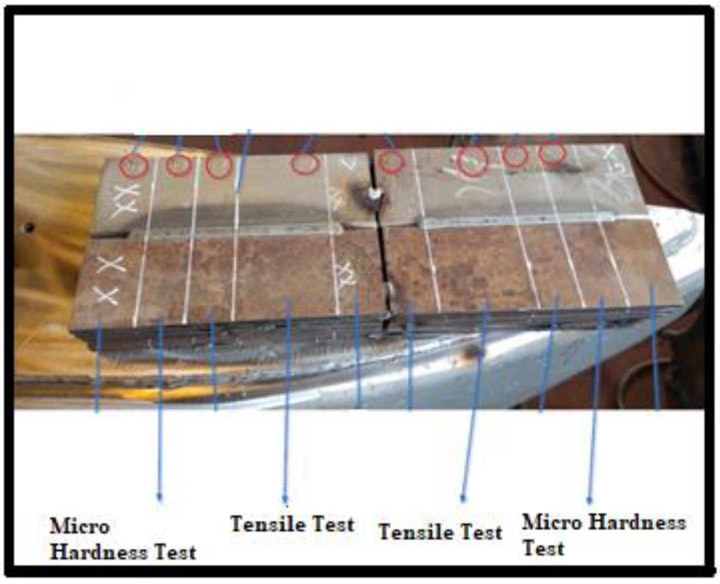

Figure 2. Representation of the areas where test samples are taken on welded parts.

3. RESULTS AND DISCUSSIONS

3.1. Microstructure Studies

Below, Figure 3 (V weld groove) and Figure 4 (X weld groove) show microstructure images of the joining areas of materials welded with a welding speed of 50 cm/min. When the obtained images are examined, the areas where the transition from the base metal to the weld metal is provided can be clearly distinguished. It can also be clearly seen that the grains formed in the weld metal are directed towards the weld metal center in the form of dendrites. The obtained images have a typical weld metal-base material transition area image and again a typical weld metal image. The grains formed in the weld metal are directed towards the weld metal center starting from the melting line and in the opposite direction to the heat flow direction. Again, from the microstructure images of the V weld groove and X weld groove joints given below, there is a traditional HAZ image on both the S355J2 material side and the HBW450 material side, and it is seen that there is no joining error or incompatibility.

When the images given below are examined in general, it can be seen that very similar microstructure images are formed in the weld areas of joints with different weld groove shapes. It can be clearly seen from the images taken from the weld metal transition and weld metal center line that the grains formed in the weld metal are very similar to each other. It has been evaluated that the reason for this is that the heat inputs are very close to each other due to the two-pass weld seam being drawn on two different weld groove samples and that both types of joints are exposed to heat inputs at similar rates, albeit at different speeds, causing these images to exhibit similarity.

Since the microstructure images of V and X weld groove joints using different welding speeds are similar, only the images of the middle value (50 cm/min) from the selected welding speeds were shared.

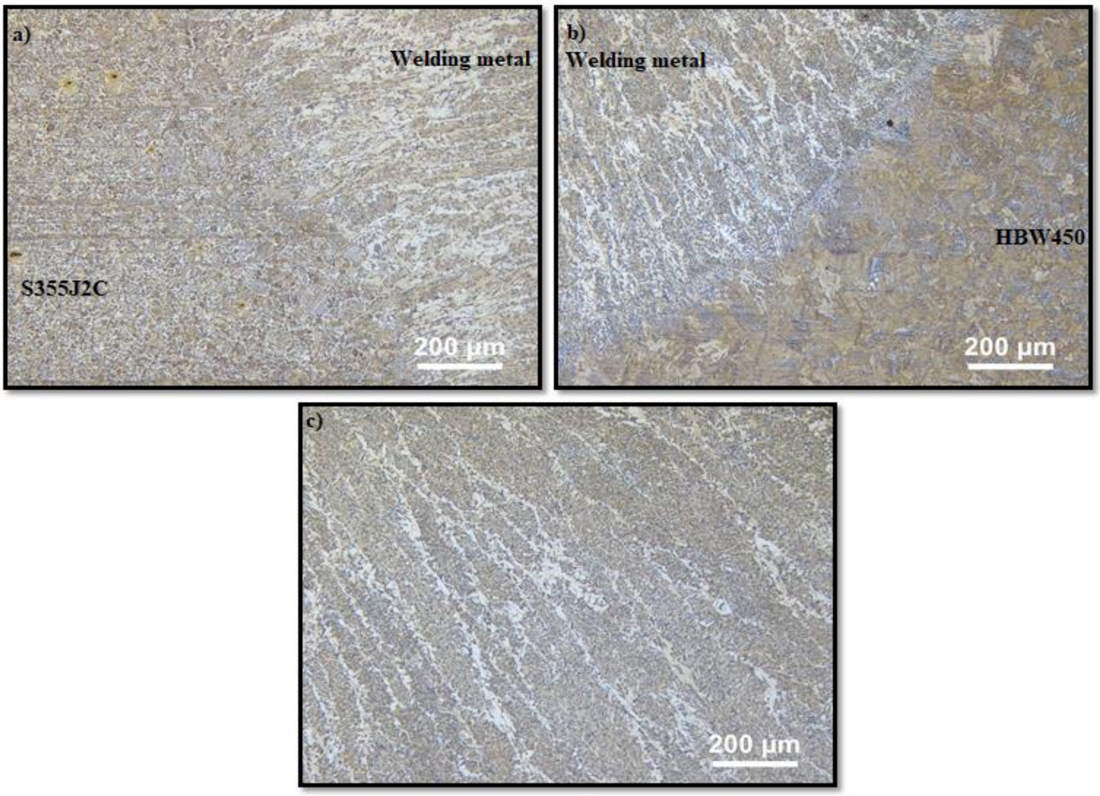

Figure 3. Microstructure images obtained from V weld groove joints. a) Transition from S355J2C material to weld metal, b) Transition from HBW450 material to weld metal, c) Weld metal center.

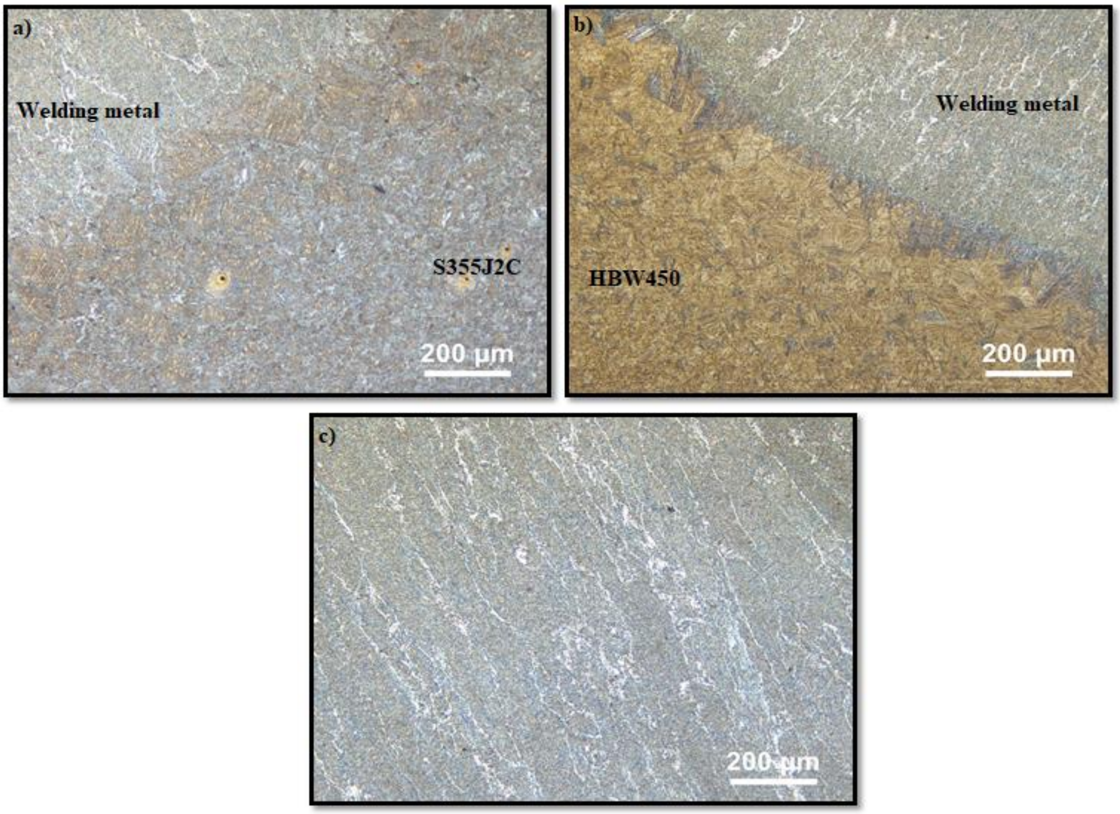

Figure 4. Microstructure images obtained from X weld groove joints. a) Transition from S355J2C material to weld metal, b) Transition from HBW450 material to weld metal, c) Weld metal center.

Yalçın et al. [13], who are working on welding different materials, have joined P265GH and P355NH materials to each other and to each other using the MAG welding method. They stated that after the microstructure examinations, they determined that the melting zone formed in the transition from HAZ to weld metal was clearly seen and also reported that the grain structure in the regions close to the weld metal of the main material became coarser and dendritic grains were formed towards the center of the weld metal.

3.2. Micro Hardness Test

In order to determine the hardness values known to play an active role on the mechanical values of the joined materials, the obtained welded samples were subjected to hardness measurement tests. The microhardness measurement results taken from the points seen in Figure 5 of the samples joined using 3 different welding speeds for V and X weld groove forms are given in Figure 6 (V weld groove) and Figure 7 (X weld groove).

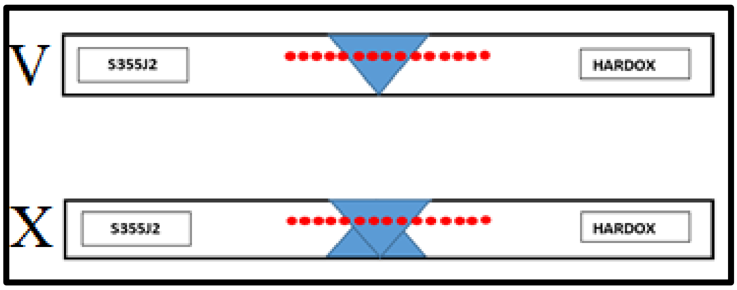

Figure 5. Points where microhardness test measurements are made.

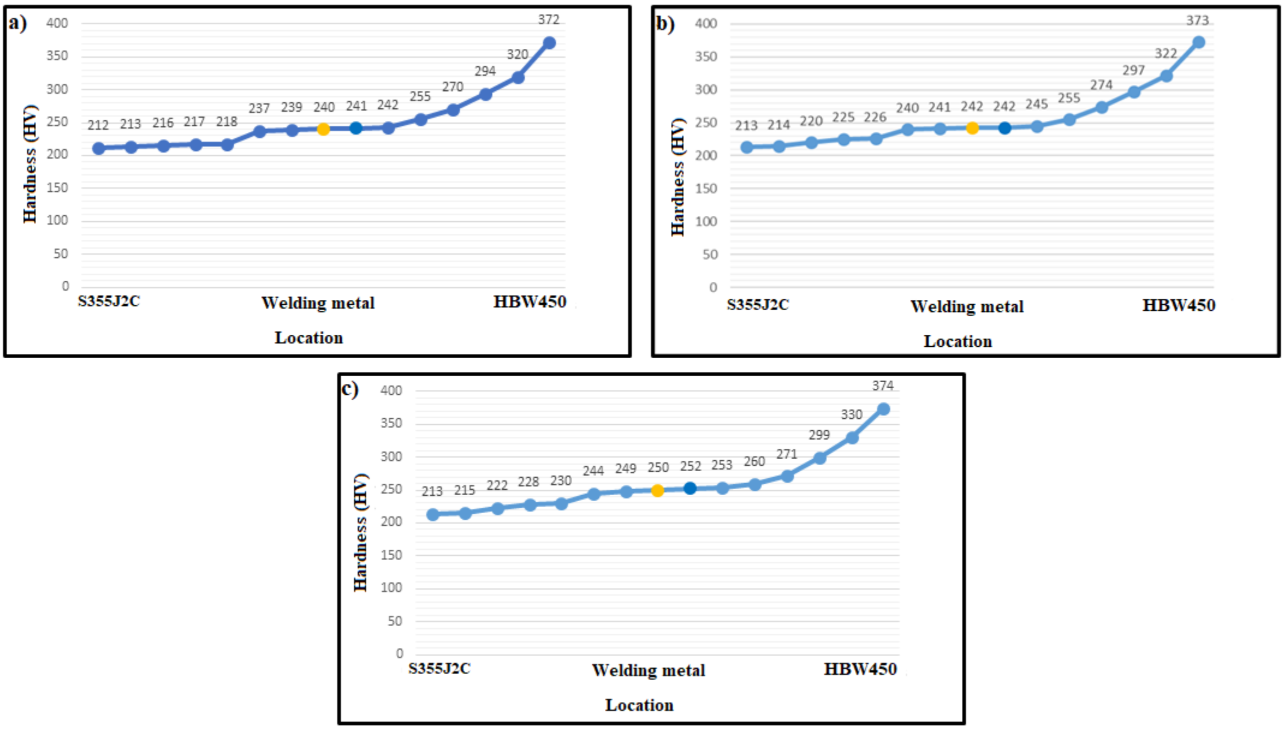

Figure 6. Microhardness test results of V weld groove joints a) 45 cm/min welding speed b) 50 cm/min welding speed c) 55 cm/min welding speed.

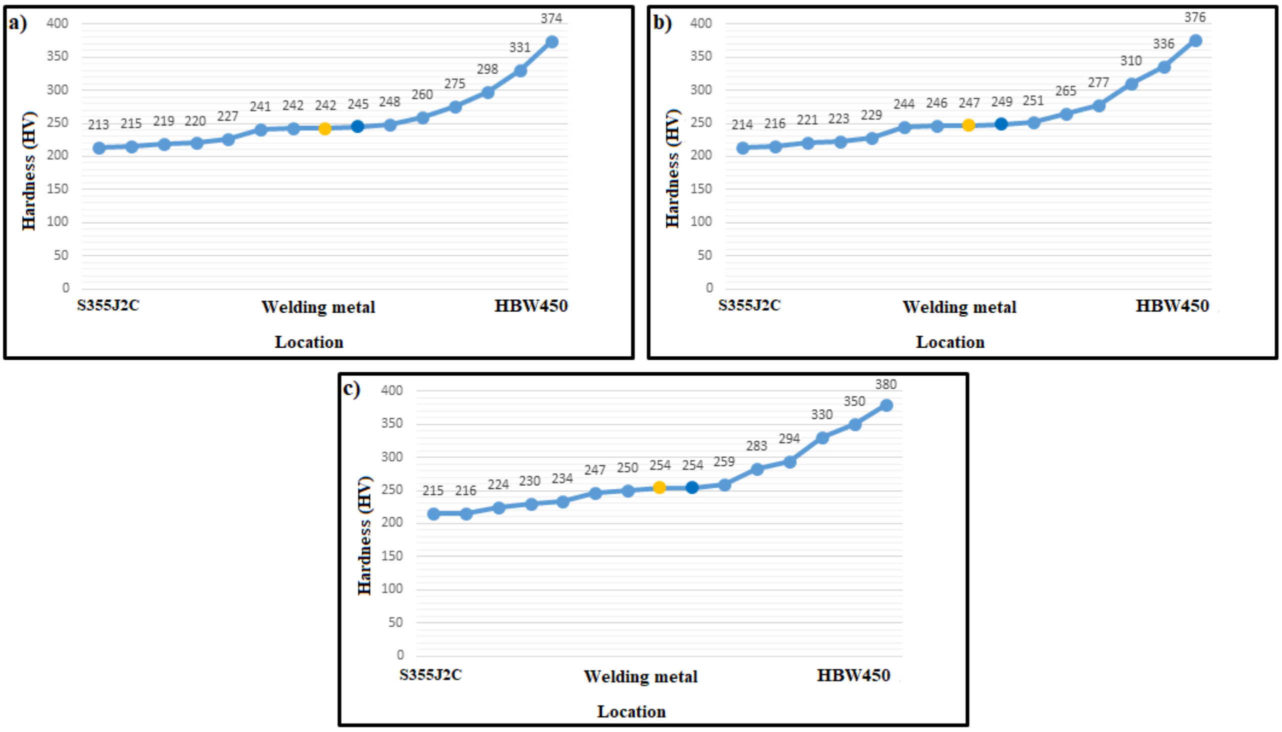

Figure 7. Microhardness test results of X weld groove joints a) 45 cm/min welding speed b) 50cm/min welding speed c) 55cm/min welding speed.

When the Microhardness test results given above are examined, it is determined that the hardness values of the weld metals are higher than the hardness values of the S355J2C base material, but lower than the hardness value of the HBW450 base material. Again, when the hardness values of the base materials to which the joining processes are applied are examined above, it is seen that the hardness value of the S355J2C material is approximately 213 $HV_{0,5}$, while the HBW450 Hardox material is 375 $HV_{0,5}$.

The highest hardness value in the weld metal is 259 $HV_{0,5}$ obtained from the joint made using the welding speed number 3 (55 cm/min) in the X welding groove. The lowest weld metal hardness value is 237 $HV_{0,5}$ obtained from the joint made using the welding speed number 1 (45 cm/min) in the V welding groove. Since the weld metal consists of a mixture of filler metal and both main materials, it is evaluated that these values are at the expected level. In this study, the hardness value of the weld metal was determined as the average of the hardness values of both different main materials. In addition, when the welded samples were evaluated among themselves, it was determined that the hardness values in the weld metals and weld regions increased depending on the increasing welding speed, although there was not much difference. Due to the different heat inputs applied to the weld regions according to the welding speed, the different cooling rates of these regions caused the hardness values to change. At high welding speeds, the heat input applied to the weld region decreased and the hardness values increased since the weld region cooled rapidly. These results showed that the weld bevel form did not have a significant effect on the hardness values of the joints.

In their study, İbrahim I. A. et al. [14] joined mild steels using different welding parameters with MAG welding technique. As a result of the examinations, it was stated that the highest hardness value was measured in the joint made using the highest welding speed. They attributed this situation to the martensite structure formed by rapid cooling as a result of the decreasing heat input with the increase in welding speed.

3.3. Tensile Test

A total of 18 tensile tests were performed, 3 for each of the samples joined using 3 different welding speeds for the V and X welding groove forms. The average of the values obtained as a result of the tests performed is given in Table 4 (V welding groove) and Table 5 (X welding groove). In addition, the graphical versions of the values obtained are given in Figure 8 and Figure 9.

Table 4. Tensile test results of welded samples using V-weld groove

	Yield Stress (MPa)	Tensile Stress (MPa)	Rupture Stress (MPa)	Elongation (%)
No. 1 welding speed	382.9	553.1	346.9	19.8
No. 2 welding speed	392.0	560.1	354.3	19.4
No. 3 welding speed	412.1	581.2	414.1	19.3

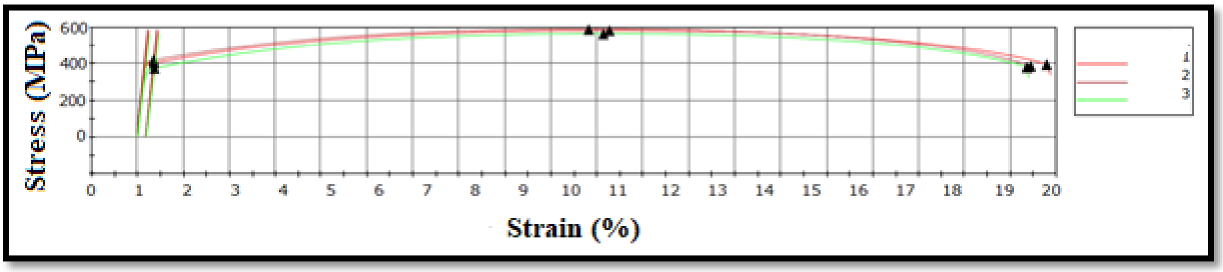

Figure 8. Tensile test results of welded samples using V-weld groove.

Table 5. Tensile test results of welded samples using X-weld groove.

	Yield Stress (MPa)	Tensile Stress (MPa)	Rupture Stress (MPa)	Elongation (%)
No. 1 welding speed	388.4	558.9	351.0	21.2
No. 2 welding speed	399.5	566.7	365.3	21.1
No. 3 welding speed	416.7	584.7	418.6	20.5

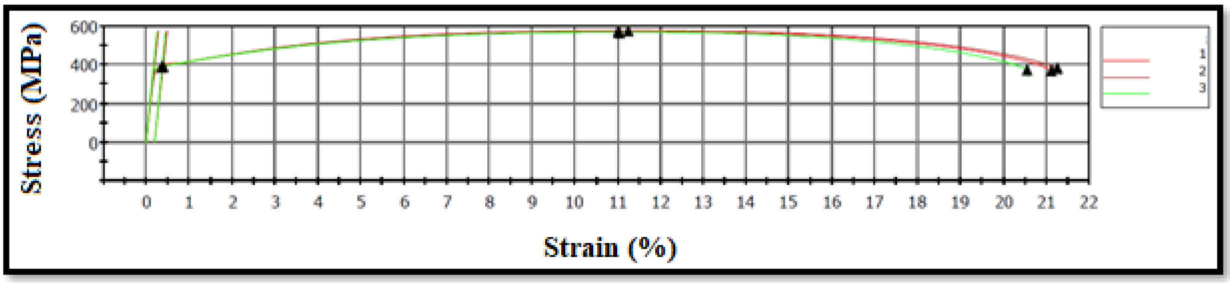

Figure 9. Tensile test graph of X weld groove samples.

When the values of the tensile graphs given above are examined, it is seen that the welded joints with V and X groove have approximately the same values. While the average maximum tensile stress value of the V groove samples is 564 MPa, the maximum tensile stress of the X groove sample is determined as 569 MPa on average.

In all tensile tests performed on welded samples, ruptures occurred from the S355J2C base material. This is an expected result since the lowest hardness values (Figure 6 and Figure 7) were measured from the S355J2C base material as a result of the hardness tests. Here, the material with low hardness values deformed and ruptured at low force values. When the results given in Tables 4 and 5 are examined, it is determined that there is a slight increase in tensile strength with increasing welding speed. It is evaluated that this situation is related to the increasing hardness values due to rapid cooling as a result of decreasing heat input with increasing welding speed.

As a result of the welding parameter values used in both types of joints (V and X) being close to each other and the heat inputs applied to the joined materials being close to each other, it is seen that the mechanical values of the joints obtained are also close to each other. It can be understood from the obtained values that the weld groove to the materials to be welded does not play a very effective role on the strength values of the materials.

In addition, it was determined that the weld groove form did not have a significant effect on the maximum tensile strength of the welded materials, as well as on the hardness values.

In a similar study, Okay et al. [15] applied tensile tests to the samples they prepared in their studies investigating the weldability of S235JR and HBW400 steel materials. As a result of the tensile tests, they stated that all the breaks occurred in the mechanically weak S235JR material.

4. CONCLUSIONS

- Within the parameters of the welding process, S355J2C and HBW450 can be joined together without any problems.
- Micrographs show that the grains in the weld metal are directed towards the centre of the weld metal in the form of dendrites. In addition, similar microstructural appearances were obtained due to the proximity of the heat inputs in the joints made using two different welding edges.
- The microhardness measurement results showed that the hardness value of the weld metal was higher than that of the S355J2C base material and lower than that of the HBW450 base material, which is the average of the hardness values of the two materials used.
- At the end of the tensile tests, all the specimens from the S355J2C base material broke. This indicated that there were no defects in the weld metal or weld area.
- It was concluded that different groove geometries do not play a very effective role in the mechanical values of the joints or the microstructure formed.

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