Karadeniz Fen Bilimleri Dergisi, 13(3), 1107-1116, 2023. DOI: 10.31466/kfbd.1295655

KFBD

Karadeniz Fen Bilimleri Dergisi
The Black Sea Journal of Sciences
ISSN (Online): 2564-7377 https://dergipark.org.tr/tr/pub/kfbd

Araştırma Makalesi / Research Article

Investigation Mechanical Properties of Shipbuilding Steel Joined By Submerged Metal Arc Welding And Gas Metal Arc Welding Methods

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Abstract

Merchant ships are generally built by joining steels with various welding methods. When the welding methods used in shipyards are examined, it is seen that gas metal arc welding (GMAW), submerged arc welding (SAW), covered electrode arc welding and tungsten inert gas (TIG) welding come to the fore. In the assembly of ship hull sheets, GMAW and SAW are generally preferred. In this sense, it is extremely important to characterize the mechanical properties of the weld zone after welding of the shipbuilding steel joined by these two welding methods. When the studies examined, although there are few studies on the joining with GMAW and SAW of shipbuilding steels, no study has been found on the comparative examination of these two welding methods. In this context, within the scope of the study, 3701 shipbuilding steel, which is used extensively in shipbuilding, was joined with SAW and GMAW methods and the hardness, tensile, impact and bending properties of the welding zone were examined comparatively. In consequence of the tests, it was determined that higher mechanical properties were obtained than the base metal in both welding methods. Also, it was found that the welding zone of the shipbuilding steel joint by the SAW method had relatively better mechanical qualities.

Keywords: Shipbuilding, gas metal arc welding, submerged arc welding, mechanical properties.

Tozaltı Ve Gazaltı Kaynak Yöntemleri İle Birleştirilen Gemi İnşa Çeliğinin Kaynak Bölgesinin Mekanik Özelliklerinin İncelenmesi

Öz

Ticari gemiler genellikle çeliklerin çeşitli kaynak yöntemleri ile birleştirilmesi ile üretilmektedir. Tersanelerde kullanılan kaynak yöntemleri incelendiğinde gazaltı kaynağı, tozaltı kaynağı, örtülü elektrod ark kaynağı ve tungsten ınert gaz kaynağının öne çıktığı görülmektedir. Gemi gövde saclarının bir araya getirilmesinde ise genellikle gazaltı kaynağı ve tozaltı kaynakları tercih edilmektedir. Bu anlamda bu iki kaynak yöntemi ile birleştirilen gemi inşa çeliğinin kaynak sonrasında kaynak bölgesinin mekanik özelliklerinin karakterize edilmesi son derece önemlidir. Yapılan çalışmalar incelendiğinde gazaltı ve tozaltı kaynağı ile gemi inşa çeliklerinin birleştirilmesi üzerine çalışmalar yapılmış olsa da bu iki kaynağın karşılaştırmalı olarak incelenmesi üzerine bir çalışmaya rastlanmamıştır. Bu yüzden bu çalışmada gemi inşaatında geniş bir kullanım bulan 3701 gemi inşa çeliği tozaltı ve gazaltı yöntemi ile birleştirilmiş ve kaynak bölgesinin sertlik, çekme, darbe ve eğme gibi mekanik özellikleri incelenmiştir. Yapılan incelemeler sonucunda her iki kaynak yönteminde de ana yapıdan daha yüksek mekanik özellikler elde edildiği saptanmıştır. Öte yandan tozaltı kaynak yöntemi ile birleştirilen gemi inşa çeliğinin kaynak bölgesinde gazaltı ile birleştirilen göre nispeten daha yüksek mekanik özellikler elde edildiği belirlenmiştir.

Anahtar Kelimeler: Gemi inşaatı, gazaltı kaynağı, tozaltı kaynağı, mekanik özellikler.

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Geliş/Received: 11.05.2023 **Kabul/Accepted:** 14.09.2023

1. Introduction

Marine vessels are generally built from composite materials, wood materials, aluminum or steel. When we look at the merchant ships in particular, it is seen that steels come to the fore due to their advantages both in strength and in the construction process (Sekban, 2021). Steels used in shipbuilding are divided into low-medium strength and high strength depending on the alloying elements they contain and the differences in production processes. Although high-strength steels provide significant advantages in terms of strength, they are relatively less preferred due to both welding difficulties and high costs. Also, low-medium strength steels are used extensively in ships due to their high weldability, easy availability and low cost. During the construction process, these steels are combined with various welding methods to form ships.

When the various welding techniques employed in shipbuilding are reviewed, it becomes clear that gas metal arc welding (GMAW), submerged arc welding (SAW), tungsten inert gas welding (TIG) and covered electrode arc welding stand out (Pamnani, Vasudevan, Jayakumar, & Vasantharaja, 2017; Pan et al., 2013; Turan, Koçal, & Ünlügençoğlu, 2011; Wu et al., 2023). While covered electrode arc welding is mostly used in narrow parts and repair processes where it is difficult for the GMAW torch to enter, TIG is generally preferred for welding stainless steels and aluminum alloys. In the panel lines, GMAW and SAW methods are generally used for the joining of the ship's outer cladding sheets. GMAW has important advantages such as having portable welding equipment, availability of many welding wires compatible with welding and low equipment cost. SAW, on the other hand, is advantageous in terms of being applied to thick steels thanks to the high heat input generated during welding and welding at higher welding speeds. Thanks to these advantages, these two welding methods have become the two most used welding methods in shipbuilding.

In ships made of steel, plates of various sizes and forms are welded together. Since it is known that significant hydrodynamic and hydrostatic loads affect ships during navigation, the mechanical properties of the welding zones should be at levels to withstand these loads in order to avoid problems during navigation. In this context, the quality of the welding area is extremely important after the welding methods used in ship construction, and many visual and mechanical tests are applied in the welding area before sailing. In addition, academic studies are carried out to determine and improve the mechanical properties of the welding area after joining the steels used in ship construction with various welding methods and welding parameters. The number of research on the joining of steels used in ship building with SAW or GMAW processes has been found to be quite little when the studies are analyzed (Donizete Borba, Duarte Flores, de Oliveira Turani, & Cardoso Junior, 2017; Gook, Midik, Biegler, Gumenyuk, & Rethmeier, 2022; Jokinen, Vihervä, Riikonen, & Kujanpää, 2000; Kim, Lee, & Choo, 2003; Sirisatien, Mahabunphachai, & Sojiphan, 2018; Wang et al., 2023;

Yuan et al., 2022; Zhang, Coetsee, Dong, & Wang, 2020a, 2020b; Zhong et al., 2023; Zhong, Li, Basu, Wang, & Wang, 2022). On the other hand, as a result of the combination of 3701 coded low-medium strength shipbuilding steel, which is used extensively in shipbuilding, with these two welding methods, it has been determined that no study has been carried out on the examination of the mechanical properties of the welding zone. In this work, shipbuilding steel was joined using SAW and GMAW techniques, and the mechanical properties of the welding zone were investigated. As a result of the examinations, it was determined that the hardness, tensile strength, impact strength and bending strength values increased after both welding methods. On the other hand, it has been determined that the mechanical values of the welding zone after SAW show better values than the welding made with GMAW.

2. Materials and Methods

In the investigation, SAW and GMAW techniques were used to join 3701 low-medium strength shipbuilding steel from Erdemir. The chemical content of the steel used in the experiment is shown in Table 1.

Table 1. Chemical content of the steel.

C	Mn	P	S	Si	Cu	Cr	V	Mo	Fe
0,16	0,7	0,01	0,008	0,18	0,03	0,05	0,05	0,13	Balance

1.2 mm diameter welding wire with basic character is used in GMAW. Also in the GMAW, the welds were carried out with a current of 220 A and a voltage of 30 V. While CO_2 was used as the shielding gas, 12 lt/min was chosen as the gas flow rate in the GMAW.

In SAW, while solid character welding wire is used, basic character ESAB welding powder is used as protective powder. While the current value used in SAW was chosen as 500 A, the voltage value was selected as 33 V.

After the welded joints, hardness, tensile, impact and bending tests were carried out on the samples removed from the weld zone as shown in Figure 1. Before the mechanical tests, certain procedures were followed in order to reduce the microcracks that may remain in the samples after cutting and affect the mechanical properties. After cutting with EDM, the samples were first sanded from coarse to fine. After sanding, the samples were polished with Al_2O_3 solution and after the absence of capillary scratches in stereo microscopes, mechanical tests were applied. Hardness measurements were made in Duramin brand hardness device using Vickers hardness measurement method. In this method, a pyramid-shaped tip with a square base is immersed under a certain load on the piece of material whose hardness will be measured, and the hardness value is determined by measuring the diagonal lengths of the trace formed after the load is removed. Measurements were made at least 3 times and the measurement averages are given in the tables. In the tensile test using a deformation rate of 5x10-4 s-1, samples were taken at least 3 times and average values were determined. Impact experiments were carried out using the Charpy notch method according to DIN 50115 standard on an Instron brand impact device with a capacity of 50 J. The tests were performed at room temperature and at least 3 repetitions for each condition, and the average values were reflected in the table. To find out how formable the samples were after welding, three point bending tests were conducted according to ASTM D790. The tests were conducted with the jaw moving at a pace of 1 mm per minute, at least three times for each condition. After the experiments, the bending force and deflection values for each condition were determined and reflected in the table.

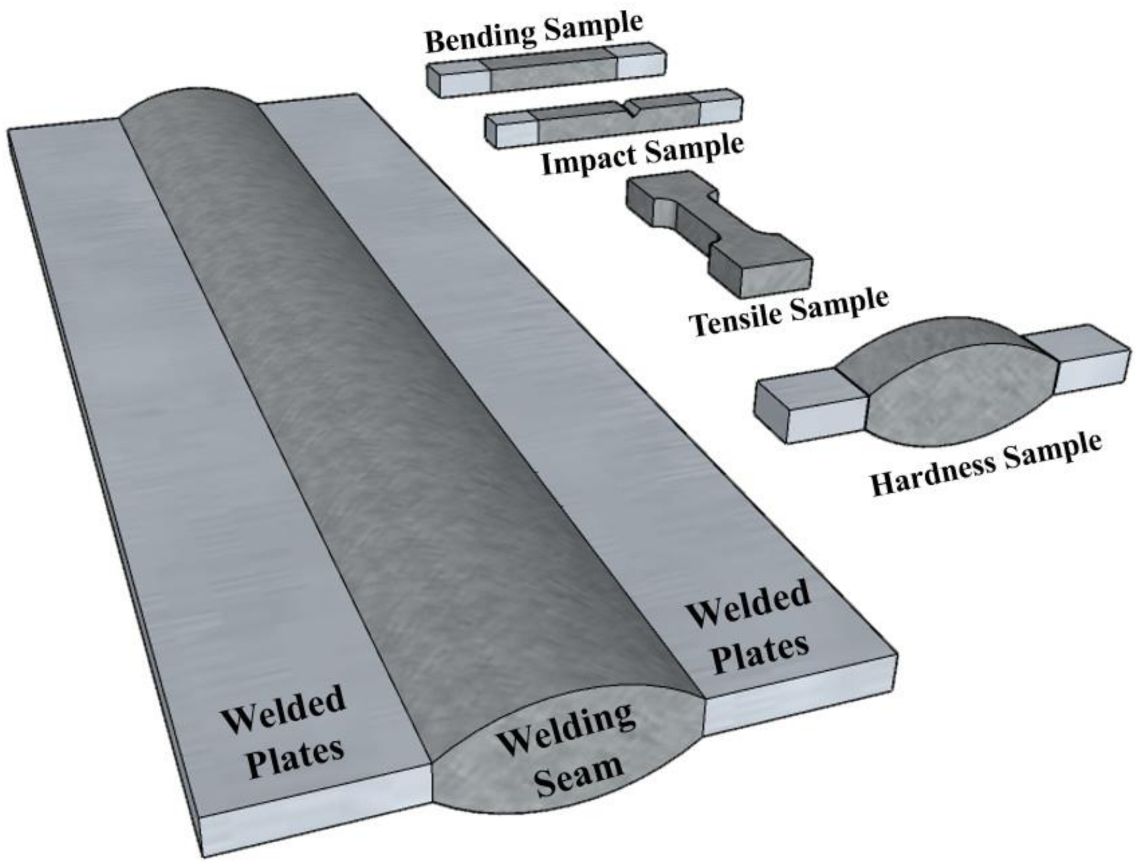

Figure 1. Schematic illustrations of test samples removed from welded plates.

3. Findings and Discussion

3.1. Hardness

The hardness values obtained from the base material, the welding zone of the steel joined by GMAW and the welding zone of the steel joined by SAW are given in Table 2. The table shows that following both GMAW and SAW, the hardness value in the weld zone increase in comparison to the base material. This situation is caused by changes in the microstructure depending on the temperature increase and cooling rate during welding. In addition, the hardness of the additional wires used in these welding methods is higher than the base material, causing an increase in the hardness in the weld area. Also, when GMAW and SAW were compared, it was determined that the hardness

value reached after SAW was higher. This is caused by the relatively lower cooling rates after SAW and the harder wire used in SAW.

Table 2. Hardness values of base material, GMAWed and SAWed samples.

Condition	Hardness (Hv)
Base material	138 ± 5
Gas metal arc welded	205 ± 7
Submerged arc welded	220 ± 9

3.2. Strength

The increase in the strength of the welded area means that the welded structure will withstand higher hydrostatic and hydrodynamic loads during the ship's navigation. On the other hand, the increase in strength in the welding area also means the need for higher forces to shape the plates after welding. In this context, it is possible to say that the strength increase of the weld zone has advantages and disadvantages. Figure 2 illustrates the strength and elongation curves for the base material, the weld zone of the steel joined by GMAW, and the weld zone of the steel joined by SAW. Also, Table 3 presents the data from these curves. As can be seen from the table, it is seen that the strength of the weld area is stronger than the base material after both welding methods, due to the post-weld microstructural changes and the use of welding wires with higher strength than the base material. Also, the highest strength values were reached after submerged arc welding due to the cooling rate decreased after submerged arc welding and the higher strength of the additional wire used in submerged arc welding. It is known that grain size decreases in the weld zone as a result of such welding methods (Hajian et al., 2015; Sekban, Aktarer, & Purcek, 2019). As a result, and as was predicted, the elongation values of the welded regions reduced following both welds.

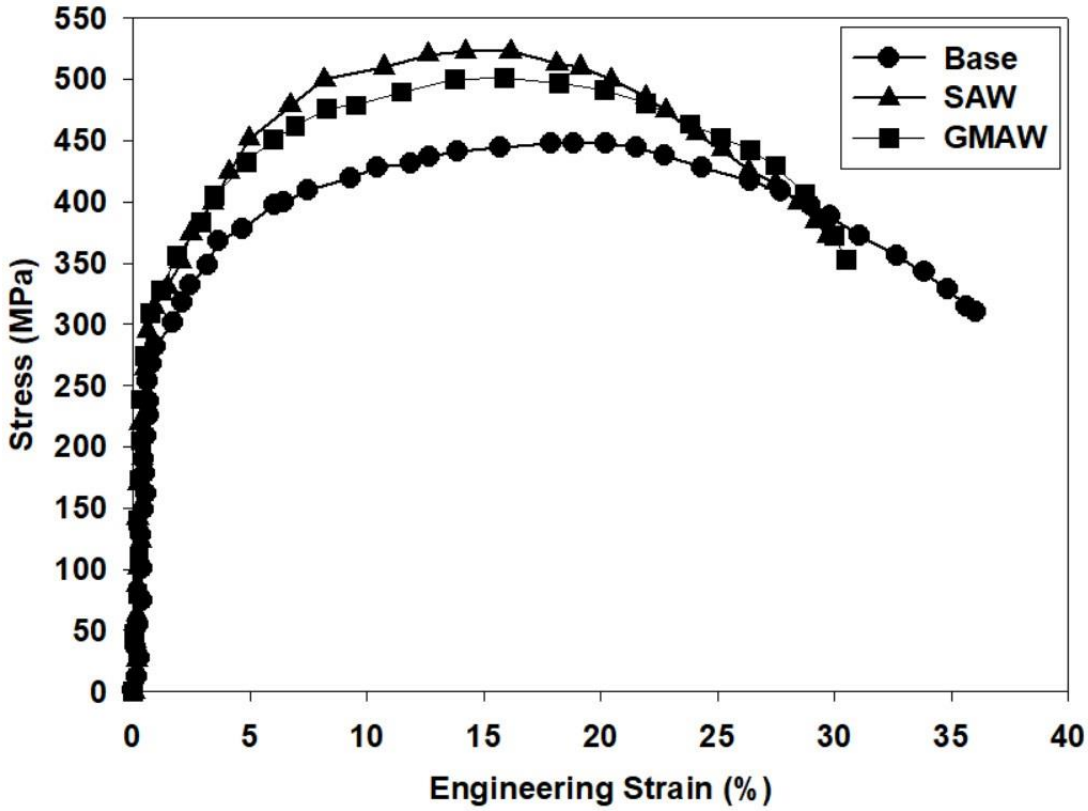

Figure 2. Stress–strain curves of base material, GMAWed and SAWed samples.

Table 3. Strength and elongation values of base material, GMAWed and SAWed samples.

Condition	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)
Base material	242±8	427±10	37
GMAW	356±11	493±11	31
SAW	371±10	513±14	32

3.3. Impact Toughness

The fracture energy of the welded areas in ships is extremely important. In this context, the impact test was performed on the samples extracted from the weld areas, and the results are shown in Table 4. As it is known, both strength and elongation values must be high in order for the strength values to be higher. As can be observed, relative to the base material, the welded regions' impact strength increased after both welds. This is because, while the elongation values have not greatly decreased, the strength values of the welded regions have increased dramatically. Also, when the

GMAW and SAW methods are compared, the toughness values reached higher levels as a result of the higher strength values achieved after the submerged arc welding.

Table 4. Impact toughness of base material, GMAWed and SAWed samples.

Condition	Impact Toughness (Joule)
Base material	7,9 ±0,9
Gas metal arc welded	8,8±0,5
Submerged arc welded	9,5±0,7

3.4. Formability

Figure 3 depicts the welding zone of the steel joined by SAW, the welding zone of the steel joined by GMAW, and the bending force and deflection curves produced from the base material. Also, Table 5 presents the results from these curves. As can be observed, the maximum bending forces increased after both welding processes. Also, due to the higher strength achieved in submerged arc welding, the highest bending forces were achieved in submerged arc welding. On the other hand, the deflection values decreased after both welds as a result of the decreasing elongation values. It is possible to examine the formability of the weld zone from two perspectives. When it is necessary to shape the welded area during ship construction after welding, the low strength of the welded area can be considered as an advantage in order to be able to shape it with lower forces. However, it will be a great advantage if the strength values of this region are high and the deflection values are low in order to prevent the ship from being deformed in the welding area during the loadings the ship is exposed to during voyage. In this context, it is possible to say that the values obtained after SAW welding are the most advantageous in terms of navigation.

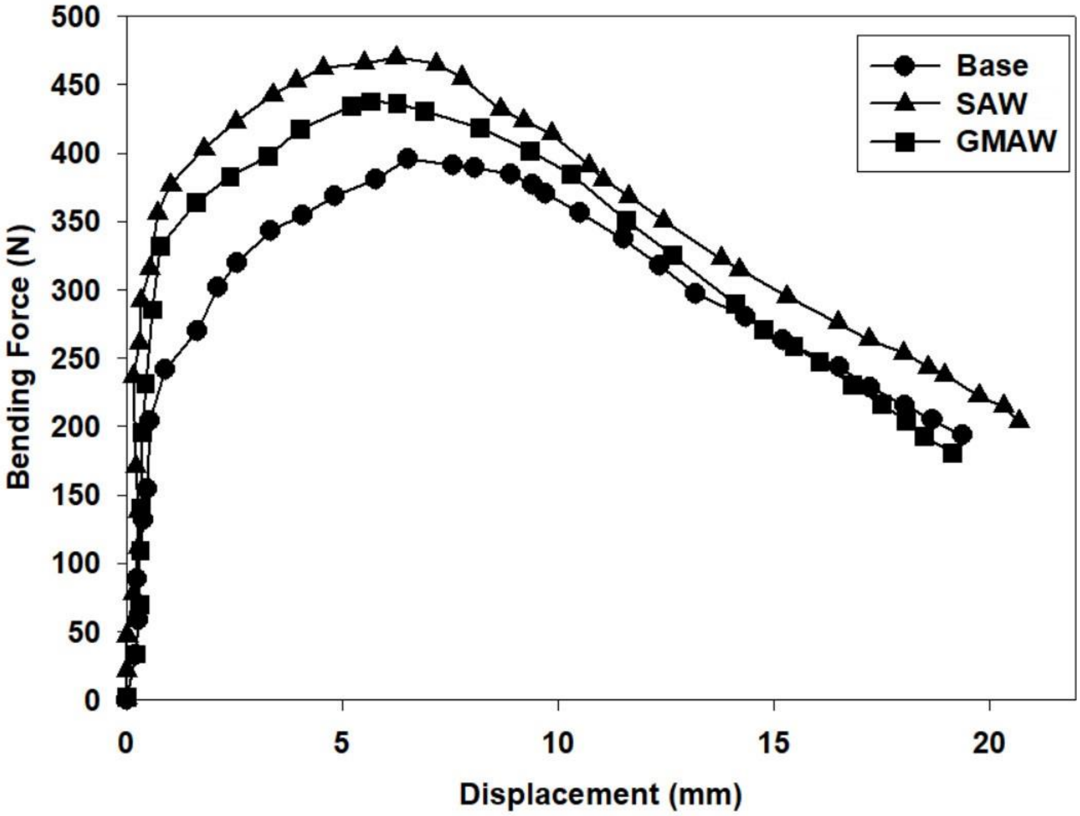

Figure 3. Bending force and displacement curves of base material, GMAWed and SAWed samples.

Table 5. Bending force and displacement values of base material, GMAWed and SAWed samples.

Condition	Bending Force (N)	Displacement at Maximum Bending Force (mm)
Base material	377±9	6,7±0,3
GMAW	448±11	5,6±0,4
SAW	471±13	6,2 ±0,4

4. Conclusions and Recommendations

In this investigation, two types of welding GMAW and SAW were used to joint shipbuilding steel and mechanical properties investigated comparatively. In consequence of the investigations the results summarized below have been achieved.

1-Both welding techniques enhanced the higher hardness value relative to the base material, and the samples joint by SAW had the highest hardness values.

2- It was determined that the strength value increased after both welds compared to the base material, however, the elongation values decreased after both welds.

3- It was determined that the fracture energy increased after both welding methods, and the highest fracture energy was reached in the sample joined with submerged arc welding.

4- After the bending test, the highest bending force was reached in the sample joined by submerged arc welding. On the other hand, it was determined that the highest deflection value was reached in the base material.

As can be seen after the study, it is possible to say that SAW welding is more advantageous in terms of strength and formability. In this sense, it would be advantageous to choose submerged arc welding in conditions where submerged arc welding can be done, such as panel lines during ship construction.

It will be useful in future studies to examine the effect of the changes in the used gas and submerged arc welding parameters on the mechanical properties. Also, examining the mechanical properties of submerged arc and submerged arc welding on different shipbuilding steels will make a significant contribution to the literature and industrial applications.

Acknowledgements

We appreciate Professor Gencaga Purcek from the Karadeniz Technical University's Mechanical Engineering Department for sharing his laboratory with us.

Authors' Contributions

All authors contributed equally to the study.

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The author declares that this study complies with Research and Publication Ethics.

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