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Analysis of HAZ with ansys in S355jr structural steels joined by flash butt welding

Yakma alın kaynağıyla birleştirilmiş S355JR yapı çeliklerinde ITAB'ın ansys ile analizi

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Highlights

- *ANSYS*
- *S355JR*
- *Flash Butt Welding*
- *Structural Steels*
- *Heat Effected Zone*

Graphical Abstract

The experimental studies were evaluated by conducting an analysis with the assistance of Ansys.

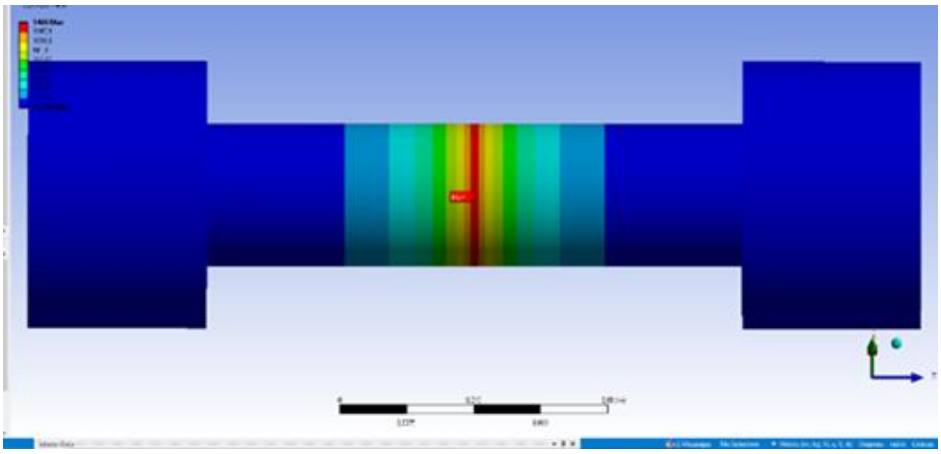

Figure. Analysis of front view after welding

Aim

The HAZ has been analyzed using Ansys during and after the welding sequence to examine the area .

Design & Methodology

Measurements taken during the welding sequence using a datalogger were evaluated with the Ansys program.

Originality

The Ansys program was employed to analyze the ITAB during welding, simultaneously with the experiments.

Findings

The Ansys program will be highly beneficial for the analysis of the HAZ.

Conclusion

The results of experimental studies align with the Ansys analyses.

Declaration of Ethical Standards

The author(s) of this article declares that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Analysis of HAZ with Ansys in S355JR Structural Steels Joined by Flash Butt Welding

Araştırma Makalesi / Research Article

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ABSTRACT

In this study, we focus on predicting factors such as temperature input and heat turbulence, which are considered to have a significant impact on the mechanical properties of the connection in welded joints, such as temperature input and heat turbulence, which may have different properties from the welding area. In the study, the flash butt welding method was preferred and holes were opened at regular intervals in the samples to be joined, and temperature values were measured using thermocouples and data loggers during the welding process. The microstructural differences occurring in the welding areas of the test pieces were examined using light microscopy and scanning electron microscopy (SEM). Microhardness measurements were also made to determine mechanical properties. Three-dimensional modeling was created using the finite element method (Ansys) under the same experimental conditions and compared with the experimental results. As a result of this comparison, it was seen that the findings were compatible with the actual results. For this reason, it is emphasized that the use of simulation programs is important to predict the properties of welded structures and possible problems.

Keywords: Flash butt welding, Ansys, thermal analysis, welding metallurgy, structural steels.

Yakma Alın Kaynağıyla Birleştirilmiş S355JRYapı Çeliklerinde ITAB'ın Ansys ile Analizi

ÖZ

Bu çalışmada, kaynaklı bağlantılarda bağlantının mekanik özellikleri üzerinde önemli etkisi olduğu kabul edilen ITAB'ın, kaynak bölgesinden farklı özelliklere sahip olabileceği sıcaklık girdisi ve ısı türbülansı gibi etmenlerin modelleme ile önceden tahmin edilmesi üzerine odaklanılmıştır. Çalışmada, yakma alın kaynak yöntemi tercih edilmiş ve birleştirilecek numunelere belirli aralıklarla delikler açılarak, kaynak işlemi sırasında termokupl ve datalogger kullanılarak sıcaklık değerleri ölçülmüştür. Deney parçalarının kaynak bölgelerinde meydana gelen mikroyapı farklılıkları, ışık mikroskobu ve taramalı elektron mikroskobu (SEM) kullanılarak incelenmiştir. Mekanik özelliklerin belirlenmesi için ayrıca mikro sertlik ölçümleri yapılmıştır. Aynı deneysel şartlarda sonlu elemanlar yöntemiyle (Ansys) üç boyutlu modellemeler oluşturulmuş ve deneysel sonuçlarla karşılaştırılmıştır. Bu karşılaştırma sonucunda, elde edilen bulguların gerçek sonuçlarla uyumlu olduğu görülmüştür. Bu nedenle, simülasyon programlarının kullanımının, kaynaklı yapıların özelliklerinin ve olası sorunların önceden tahmin edilebilmesi için önemli olduğu vurgulanmıştır.

Anahtar Kelimeler: Yakma alın kaynağı, ansys, termal analiz, kaynak metalurjisi, yapı çelikleri.

1. INTRODUCTION

In general, it is desired that the mechanical properties of the ITAB region are minimally affected by the welded structure. Therefore, the burning arc welding method has been chosen to examine this critical region, particularly for the safety of the welded structure, to determine the mechanical properties of HAZ. [1-3]Structural steels are important in terms of availability and weldability. In this study, S355JR structural steel, a widely used material with good weldability, has been employed. In contemporary welding applications, knowing the temperature distribution in the heat-affected zone and the weld zone in advance is crucial. Pre-determining this information allows for taking precautions against potential issues in welded joints, saving time and costs, and improving the overall quality of the work [4-6]. Welding creates significant temperature differences in and around the welded area due to the heat it generates. In arc welding, three distinct zones are typically observed within the welded joint: the fusion zone, the heat-affected zone, and the base metal. During welding, a substantial temperature gradient arises in the vicinity of the welded region as a result of the heat produced. The objective of this article is to present the thermal cycle simulation technique and its usefulness for the study of the heat-affected zone. An X70 steel was chosen to undergo thermal treatment cycles using the simulation equipment. It has been shown the importance of this technique for the study of HAZ. It was found that the microstructure of HAZ depends on the heating temperature [7].

Ebrahimpour et al. conducted a study to investigate the influence of resistance spot welding parameters and heat-affected zone (HAZ) on various aspects of steel joints. 3D coupled thermal-electrical-structural finite element

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method (Ansys) was used to simulate RSW. The welding zone boundaries were established by considering critical temperatures, and responses across all samples were computed. Utilizing analysis of variance, the direct, quadratic, and interactive impacts of the parameters on the responses were scrutinized, culminating in the formulation of a distinct mathematical model for each response. In particular, current density had the most significant impact on all responses [8].

It is essential to be aware of the problems that may occur due to temperature changes in welded joints before proceeding to the manufacturing stage, in terms of time, cost, and quality of work [9-10].

In the engineering realm, Ansys stands out as a commonly favored simulation software, renowned for its versatility and effectiveness. Typically employed post-modeling phase, Ansys enables engineers to conduct comprehensive testing within a virtual environment before physical prototype production, thereby streamlining the design iteration process and facilitating informed decision-making [11].

In the study of Tanürün et al., the effect of the beam structure on aerodynamic performance in the NACA 2412 model, which is widely used in wind turbine airfoils, was numerically examined. Airfoils modeled with the Rhinoceros Program Were Analyzed Using The Ansys Fluent program. Numerical analyses were carried out using the k-ε realizable turbulence model at 3.24x105 Reynolds number (Re) [12].

Koçak et al. conducted an optimization study focused on the fork component, a crucial sub-element of the aircraft nose landing gear, aiming to enhance performance and design, decrease weight, minimize material waste, and lower process energy consumption. Utilizing the Ansys Workbench program, the analysis entailed setting up requisite boundary conditions for optimizing the fork part. Post-optimization, the structural integrity of the fork was validated by comparing stress and deformation profiles with pre-optimization results. Structural modifications led to a weight reduction, affirming the optimization process's efficacy [13].

Erdemir et al. conducted a study to assess the mechanical properties of a composite material and analyze its impact on I-type snap-fits using Ansys software. The composite material's mechanical properties were evaluated, revealing a decrease in density and tensile strength. Through Ansys analysis, it was determined that the composite I-type snap-fit design of equivalent dimensions could withstand 12.6% less force when the material reaches its maximum values, specifically at the elongation at the breakpoint [14].

In the study of Dauod et al, 304 stainless steel TIG welded joints with ER308L and ER310 fillers with and without mechanical vibration microstructural and mechanical properties variations. SEM and optical microscope were employed to analyze weld joints microstructure with and without vibration. Research results illustrated that welding with mechanical vibration decreases columnar dendrites ' number and length, and weld metal microstructure shifts from columnar to equiaxed dendrites. Decrease in dendrites average size from 547.42 µm to 64.32µm for ER308L weld metal and from 663.87 µm to 63.41 µm for ER310 weld metals dedicated in an investigation. Unmixed zone formation near the ER310 filler welding zone fusion line was observed in specific zones and disappeared with others. Ansys model for welding zone and HAZ of ER308L and ER310 fillers applied by Goldak model used to investigate effects of vibration on welding zone parameters and maximum welding heat to understand welding heat influence on welding zone and HAZ [15].

To achieve this goal, an experimental investigation of the welding zone of the components is planned. The obtained experimental results will be compared with modeling using engineering simulation software such as Ansys, commonly used in the field. This software is typically used after the modeling stage, allowing virtual testing before the production of prototypes. Simulation of welded structures is one of the most significant aspects of studies related to welding processes. In this study, a comparison is made between the actual and virtual temperature distribution in welded structures.

2. MATERIAL METHOD

2.1. Material

Experimental studies were conducted using Ø20x100 mm dimensions of S355JR structural steel material. The chemical composition of the S355JR steel used is given in Table 1. The centers of the drilled holes were determined to be 1 cm apart (Figure 1).

Table 1. Chemical composition of material S355JR.

(%) Chemical composition					
C	Si	Mn	P	S	Cu
0,24	0,16	1,30	0,045	0,0020	0,004

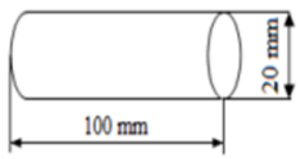

Figure 1. Dimensions of the weld sample

2.2. Method

Samples were prepared in the dimensions shown in Figure 1 and were connected to the welding machine as depicted in Figure 2. Welding processes were carried out under the parameters provided in Table 2. The processing steps are provided in Figure 3.

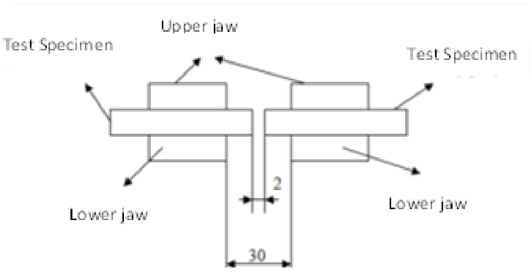

Figure 2. Binding of samples to the jaw

Table 2. Parameters used for the welding process

Preheating Time (s)	3
Voltage (V)	3
Amperage (A)	30
Strike Pressure (Bar)	2
Build-up Pressure (Bar)	3
Jaw Clamping Pressure (Bar)	3
Build-up Flow Time (s)	2

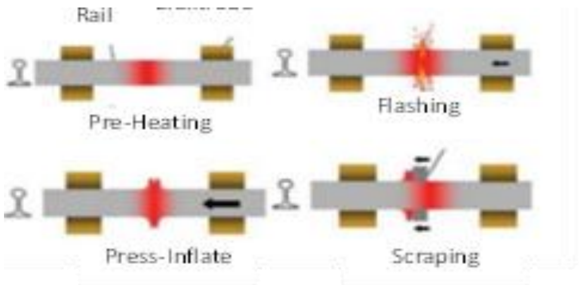

Figure 3. Flash butt welding process steps [8]

3. EXPERIMENTAL STUDIES AND RESULTS

3.1. Temperature Measurement

Before starting the welding process, thermocouple tips were placed in the holes previously opened at 1 cm intervals after the material was properly positioned in the machine. These thermocouple tips were used with a suitable datalogger to record temperature changes during the welding and cooling process.

Figure 4. Arrangements of thermocouples on the sample

During the welding process, temperature measurements using thermocouples and a datalogger were carried out simultaneously with the use of a thermal camera to determine the maximum temperature reached in the welding zone.

As seen in Figure 4, the thermocouple closest to the welding center is T2, while the furthest one is T8.

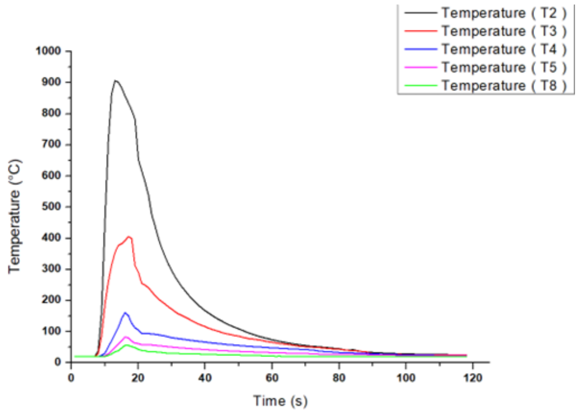

Figure 5. Temperature graphs measured with thermocouples

As observed in Figure 5, the thermocouple T2, which is closest to the weld metal, has measured the highest temperature values. Upon examining the figure, it is evident that this temperature exceeds 900°C. On the other hand, the T8 thermocouple, located furthest from the welding center, recorded a temperature of approximately 100°C. As one moves away from the welding center, the peak temperature decreases, and the cooling time shortens. Additionally, there is an approximate temperature difference of 500°C between T2 and T3, about 250°C between T3 and T4, around 80°C between T4 and T5, and approximately 30°C between the last two thermocouples.

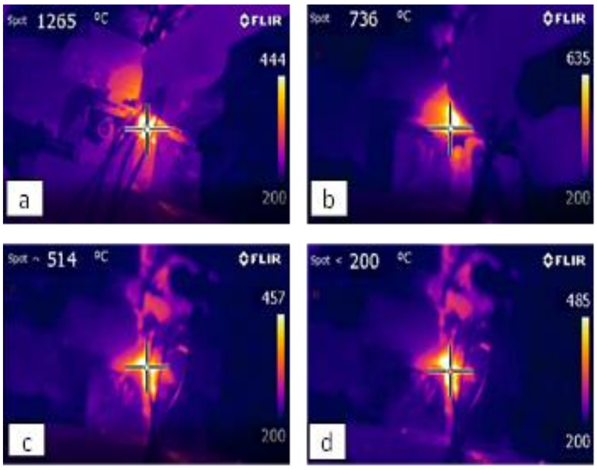

Figure 6. Thermal camera images.(a) Welding Center., (b) HAZ, (c) Transition Zone, (d) Main Material

During the welding process, temperature measurements were taken with a thermal camera. Temperature measurements were obtained from areas near the welding center and other thermocouple points. Upon examining the thermal camera image taken from the welding center, it was determined that the maximum temperature reached 1265°C (Figure 6).

3.2. Hardness Measurement

In this study, hardness measurements were conducted under a 5 kgf load. Measurements were taken from three different regions, considering the welding zone as "0," progressing from both sides towards the HAZ (Heat-Affected Zone) and the base material.

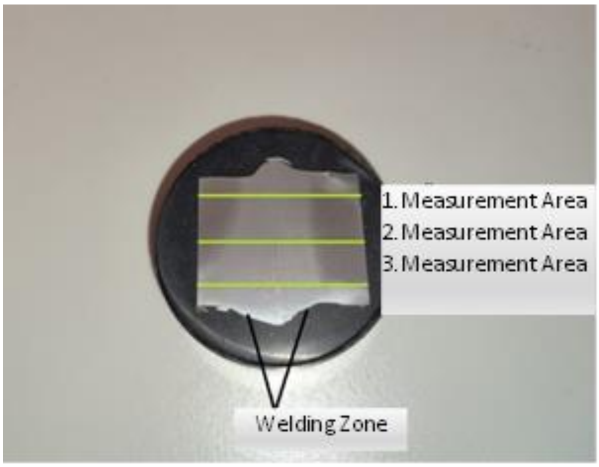

Figure 7. Regions where hardness testing is performed

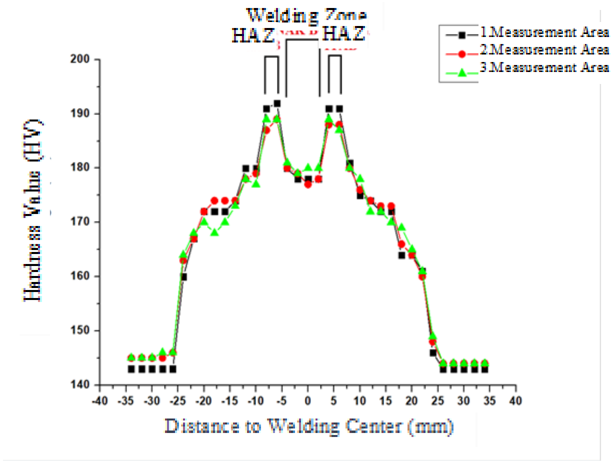

Figure 8. Graph of hardness test results

When the hardness graph is examined (Figure 8), it is seen that an average hardness value of 178 Vickers is obtained in the weld center and 195 Vickers in the HAZ region. Hardness values decrease as you move towards the main material. This can be attributed to the characteristics of the combustion arc welding process, which include high heat input, slow cooling, and pressure ejection of the molten zone. This removal can lead to the removal of various inclusions and defects from the melted region, leading to lower hardness values. In the HAZ region, it is thought that the cooling rate exceeds the critical cooling rate, resulting in higher hardness values. The temperature difference of approximately 500°C between T2 and T3 measured with thermocouples supports this observation.

3.3. Microstructure Results

The microstructure images obtained from the samples under the optical microscope as a result of the performed metallography processes are provided below. The regions where the microstructure images were taken are also indicated on the sample in Figure 9.

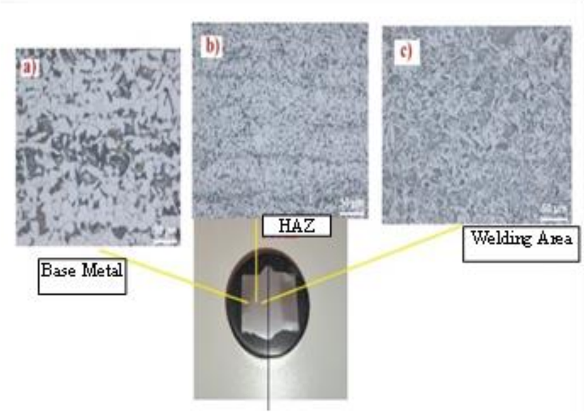

Figure 9. Demonstration of the areas where the microstructures are taken on the sample. a) Base metal b) HAZ c) Weld metal

As shown in Figure 9, in Region A, where there is no temperature change, no observable alteration has been detected in the microstructure. In other words, no transformation has taken place.

Region B is the Inter-Critical Heat-Affected Zone (HAZ), influenced by heat near the weld metal. In this region, it is noted that pearlitic colonies have reduced in size compared to the base material, and there is a somewhat more homogeneous distribution between ferritic phases.

Region C is the weld metal. Upon examination of this region, the microstructure is observed to consist of fine and elongated dendritic grains. These fine and elongated grains, resembling a needle-like structure, can be characterized as an acicular ferrite structure.

For a more detailed view of the structures formed during the microstructure analyses, the structures were shown.

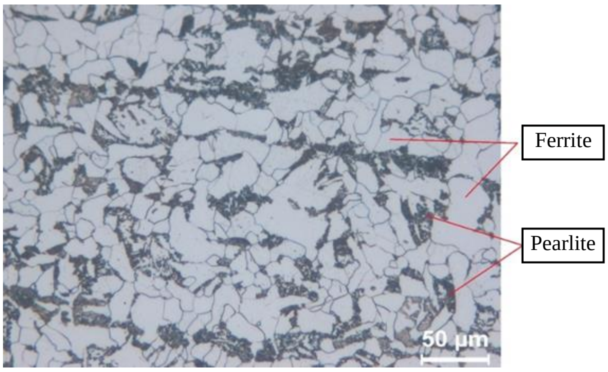

Figure 10. Image of the region that has not undergone heat change (base metal)

As seen in Figure 10, there is no microstructural change in the region farthest from the welding zone. The material consists of a mixture of Ferrite and Perlite structures, which are the microstructure of the base metal.

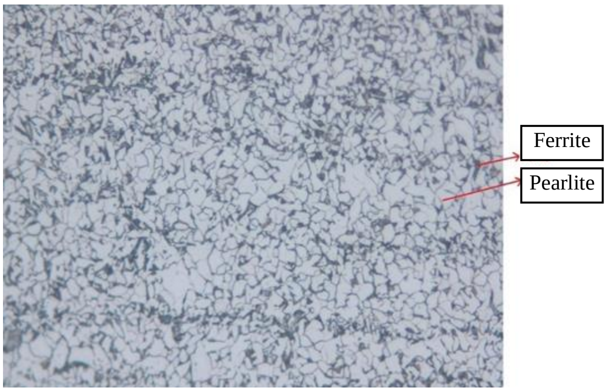

Figure 11. Image of the area under the influence of heat (HAZ)

As shown in Figure 11, due to the intense heat and rapid cooling in the welding zone, a region with changes in the internal structure emerges. In this area, it is observed that pearlitic colonies are smaller compared to the base material, and there is a somewhat more homogeneous distribution between ferritic phases compared to the base metal.

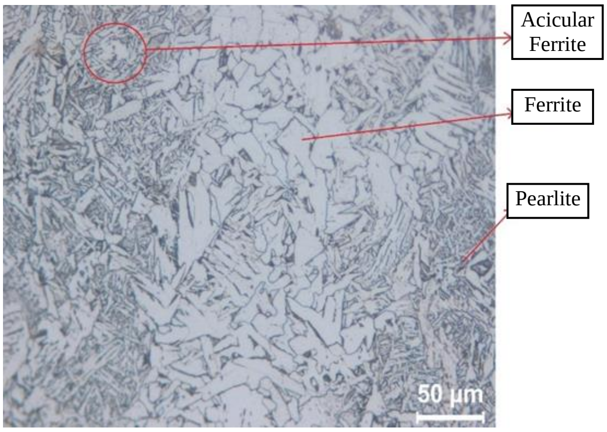

Figure 12. Image of the weld metal.

When examining the microstructure of the welding zone observed in Figure 12, a dense ferritic structure is observed at the fusion surfaces. Additionally, right next to the fusion line, there is a coarse-grained structure composed of acicular ferrite and Widmanstätten ferrite in some areas. The grain structure in these regions consists of fine and elongated dendritic grains. The resulting fine and elongated grains, resembling a needle-like structure, can be characterized as an acicular ferrite structure.

In the experimental studies, Scanning Electron Microscope (SEM) images were obtained from the parts joined by the burning edge welding method.

In this section, clearer views of the microstructure images were obtained using a Scanning Electron Microscope (SEM). The dendritic structure in the welding zone is visible in these images (Figure 13b).

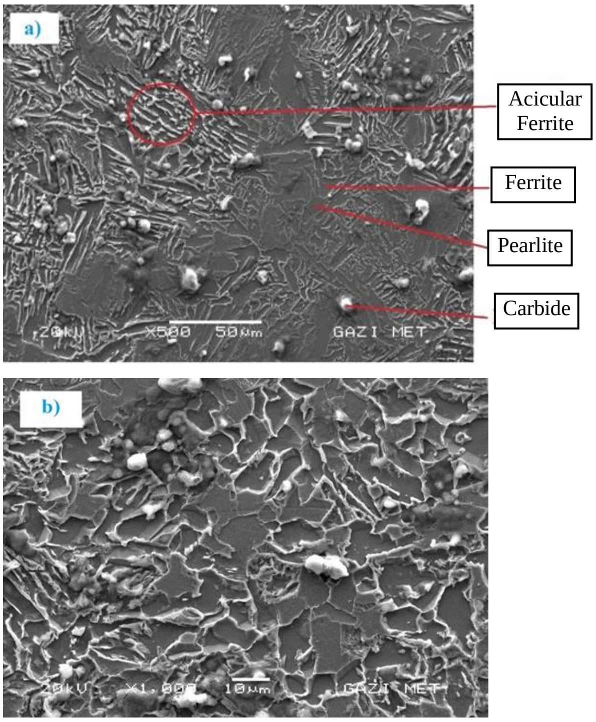

Figure 13. SEM Image of the weld metal

3.5. Ansys Study

The samples used in the experimental studies were replicated in Ansys with the same process conditions and in one-to-one dimensions. The solution of the model in Ansys was carried out following the welding sequence plan. The data required for the welding process were kept the same as the experimental data used in the studies (Figure 14).

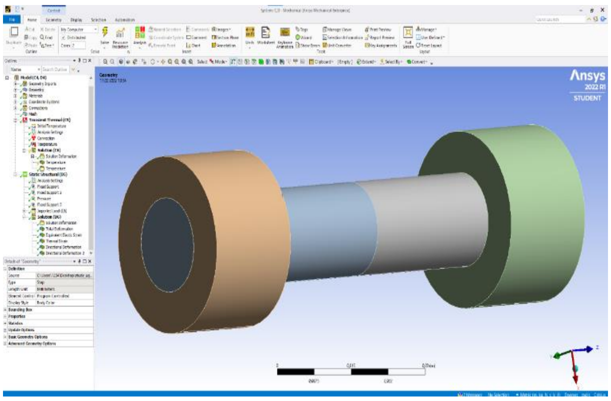

Figure 14. Creating the model

During the model creation, in addition to the samples that underwent welding, the jaw holders of the burning edge welding machine were also included in the modeling. After the modeling process, material properties were assigned to the program. The Ansys program inherently knows the properties required for many materials. S355JR structural steel is one of them, and hence, no additional manual intervention was needed as the program automatically recognized this material. The mechanical properties of the S355JR material are provided in Table 3.

Table 3. Mechanical properties of S355JR

Elasticity modulus (N/mm²)	2,10E
Poisson's ratio (N/A)	0.28
Rupture modulus (N/mm²)	7.9E
Density (kg/m³)	7,80E
Tensile strength (N/mm²)	4,50E
Yield strength (N/mm²)	2,75E
Thermal expansion coefficient (1/K)	1.1E
Thermal conductivity (W/(m·K))	1,40E
Specific heat (J/(kg·K))	4,40E

After defining the material properties, the parameters used during the experiment were specified in the program. Once the necessary definitions were made, the burning edge welding simulation was conducted, followed by thermal analysis after the completion of the welding process (Figure 15-16).

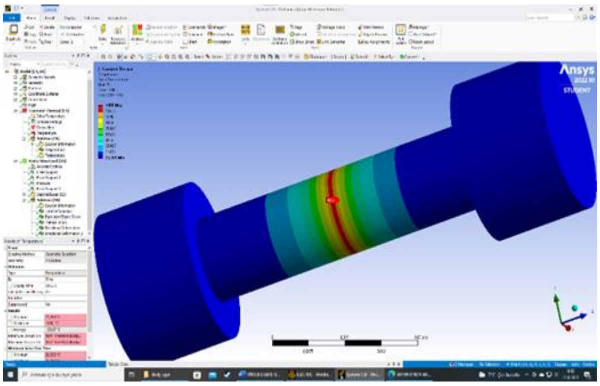

Figure 15. Thermal analysis after welding

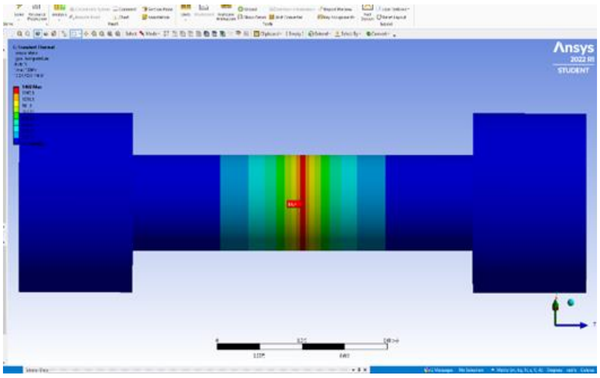

Figure 16. Analysis front view after welding

As seen in Figure 16, after thermal analysis, the materials joined edge to edge reached the maximum temperature in the full edge region. The maximum temperature recorded with the thermal camera during the experimental studies is 1265 °C. After thermal analysis with Ansys, the maximum temperature reached was determined to be 1400 °C. Even slight changes in the emissivity angle of the thermal camera can cause variations in the measured temperature values, and the difference of 135 °C between the two values is within an acceptable tolerance.

Following the thermal analysis, results close to the temperature values measured with thermocouples during experimental studies were obtained. As one moves away from the welding zone, the measured temperature values are 1247 °C, 1094 °C, 941 °C, 789 °C, 636 °C, 483 °C, 330 °C, 178 °C, respectively (Figure 17).

It is observed that these obtained temperature values are close to the values obtained during the experimental studies.

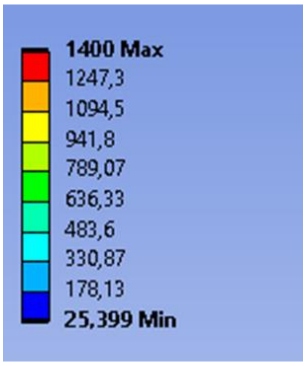

Figure 17. Temperature values obtained after thermal analysis

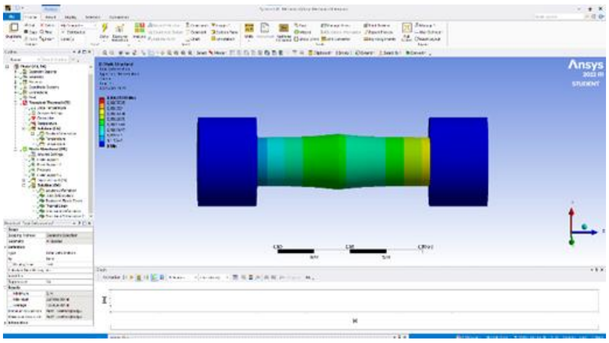

Figure 18. Total deformation analysis

The analysis results using experimental parameters indicate dimensional changes. During the welding process, due to the application of force on one of the jaws, some swelling and dimensional shrinkage occur in the edge region. After the total deformation analysis, it is observed that the total dimension loss is approximately 6 mm (Figure 18).

Figure 19. Accumulation in the test sample

When examining the experimental samples, it was determined that the distortions in the materials after welding were approximately 6-7 mm (Figure 19). The results obtained from the Ansys analyses are consistent with this. Since ideal criteria could not be achieved throughout the welding process in the experimental studies, it was not expected for the Ansys results to be identical. However, the proximity of the obtained results indicates successful analysis results.

4. RESULTS

1. The grains formed in the HAZ region are oriented towards the center of the welding metal in the opposite direction of the heat flow.
2. The grains formed in the welding metal are a continuation of the base material grains since a different joining material is not used. The welding metal does not contain significant defects such as pores or oxides.
3. Due to the effects caused by pressure, resistance, and cooling conditions affecting the welding zone, no cracks have formed.
4. While a dense ferritic structure is present on the joining surface, a large-grained structure consisting of acicular ferrite is found just next to the fusion line. In the transition zone, these structures persist but with a more homogeneous appearance.
5. The experimental and Ansys analysis results are similar, providing close results even if not entirely identical.
6. The thermal mobility resulting from the welding process in the parts to be joined can be predicted in advance using the Ansys program. This ability to make predictions in advance will contribute to reducing potential errors in the design and, consequently, to material and time savings.

In this study, the results of the experimental studies were analyzed with the help of Ansys and it was seen that they supported each other. As a result, modeling experimental studies with the Ansys analysis program and analyzing them in Ansys before starting production will make it easier for the manufacturer to detect possible errors in advance and provide information on preventive measures. Incorrect or missing values during analysis may prevent the analysis from being accurate and complete. Detection of welding-related problems such as thermal mobility, residual stresses, and distortions can be accomplished more economically using computer programs.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declares that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

YAZARLARIN KATKILARI (AUTHORS' CONTRIBUTIONS)

Uğur ARABACI: Perofrmed the experiments and analyse the results. Wrote the manuscript.

Gazi Emre KOCAMANOĞLU: Perofrmed the experiments and analyse the results.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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