

# ENHANCING WELD JOINT INTEGRITY IN S460 HIGH-STRENGTH STEEL PLATES: AN EXPERIMENTAL APPROACH

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## Abstract

Exploring S460 steel, this research assesses weld toe microstructure and fatigue. It finds that welding affects hardness of welded area and fatigue life. These insights are crucial for structural engineering, optimizing welding practices for longevity.

Tests confirm increased weld toe hardness correlates with fatigue resistance. This informs design strategies, ensuring bridge safety under cyclic loads. The study advances understanding of HSS behaviour, influencing future welding techniques.

## Keywords

High-strength steel, weld's toe, cruciform joints, S460, fatigue behaviour

## 1 INTRODUCTION

The application of high-strength steels (HSS) in structural engineering has been a subject of increased interest due to their potential to enhance the performance and sustainability of critical infrastructures such as bridges and high-rise buildings. Particularly, the S460 grade steel, characterized by its high yield strength and excellent ductility, offers promising opportunities for the construction of more slender and lighter structures while maintaining safety and resilience [1], [2].

One of the critical aspects of utilizing high-strength steels in construction is the integrity of welding joints. Welds are ubiquitous in steel structures, yet they are often the weakest link due to the heterogeneity in mechanical properties that can arise from thermal cycles during the welding process. The area adjacent to the weld's toe is especially susceptible to the formation of microstructural anomalies which can significantly influence the fatigue life of the structure [3], [4].

This study aims to dissect the intricate changes that occur in the material properties near the weld's toe of S460 steel plates with cruciform joints. By employing a robust experimental framework, the research seeks to provide a comprehensive understanding of how welding parameters and thermal cycles interact to affect the microstructure and, consequently, the mechanical behaviour of the welded joint. The overarching goal is to synthesize this knowledge into actionable insights that can guide the optimization of welding practices for enhanced structural integrity and longevity.

## 2 METHODOLOGIES

### Material

To explore the effects of welding on the fatigue behaviour of S460 high-strength steel plates, a series of controlled experimental procedures were conducted. The chemical composition and mechanical properties of the steel, specifically designed for load-bearing structures in civil engineering, were assessed to establish a baseline for subsequent analyses. And the chemical composition of our S460 as it was provided by the producing company showed in Tab. 1.

Tab. 1 S460 – Chemical composition.

#	Set values max.	Measured values
C [%]	0.2	0.171
Si [%]	0.6	0.472
Mn [%]	1.7	1.68
P [%]	0.025	0.016
S [%]	0.02	0.0007
Al [%]		0.019
Cr [%]	0.3	0.036
Ni [%]	0.8	0.02
Mo [%]	0.1	0.013
Cu [%]	0.55	0.009
V [%]	0.2	0.115
Nb [%]	.05	0.003
Ti [%]	0.05	0.002
N [%]	0.025	0.025
B [%]		0.003

The tensile properties of the material were determined in accordance with standardized testing procedures [5], including the measurement of yield stress and ultimate tensile strength [6], and the results can be shown in Fig. 1. The Vickers hardness test [7], reliable indicator of material resistance to deformation [8], was performed to evaluate the hardness variations in the weld area and the base material and the testing results are shown in Tab. 2.

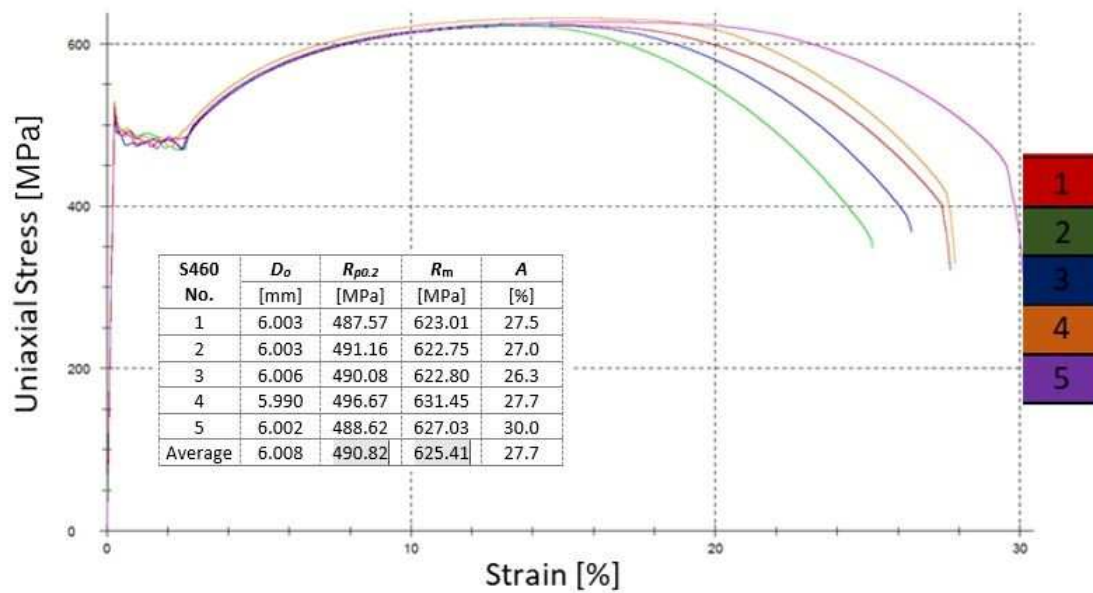


Fig. 1 Stress-Strain Diagram for S460 and table of evaluation for 5 coupons.

Tab. 2 Vickers Hardness Test Results for S460.

2 mm Horizontal Shift				2 mm Vertical Shift			
#	<i>d1</i>	<i>d2</i>	HV1	#	<i>d1</i>	<i>d2</i>	HV1
1	101.6	102.7	178	1	101.4	101.7	180
2	98.86	100.2	187	2	101.1	100.8	184
3	102.2	102.9	178	3	100.9	99.79	184
4	98.23	99.38	190	4	101.6	102.7	178
5	85.48	88.13	246	5	102.4	102.3	177
6	88.62	91.46	229	6	97.4	95.83	199

Fatigue tests were carried out to develop the *S-N* curve for the material [9], which characterizes the relation between the cyclic stress amplitude and the number of cycles to failure. These tests provide critical insights into the material's fatigue life under repeated loading conditions typical of structural applications, and the results for *R* = 0.1 can be seen in the *S-N* curve shown in Fig. 2.

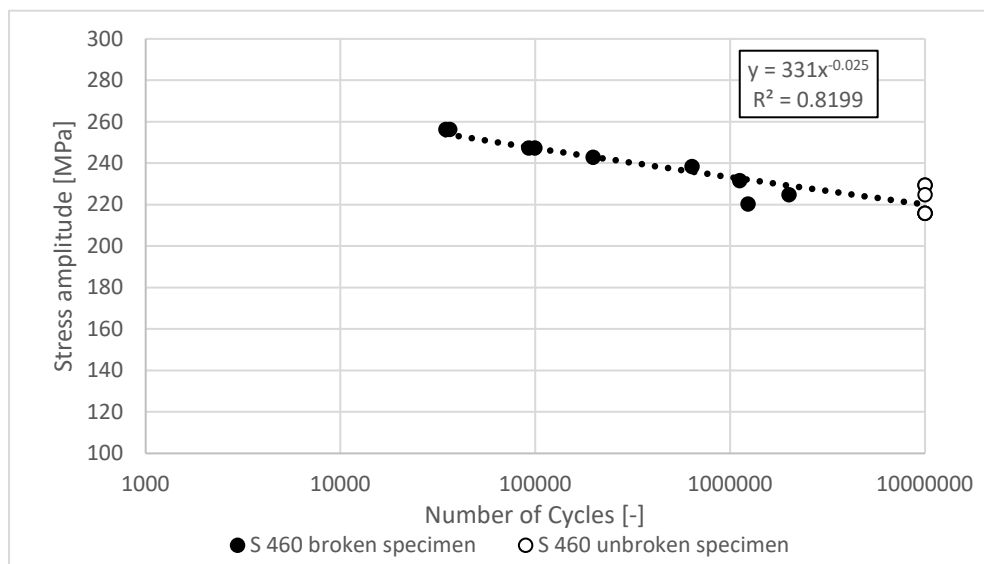


Fig. 2 *S-N* Curve for S460 stress ration 0.1.

## Welded Parts

Finally, the S460 steel coupons were prepared for fatigue and Vickers hardness testing to evaluate weld joint performance. Submerged arc welding was applied under optimized conditions to replicate industrial practices. Post-weld heat treatment was conducted to reduce residual stresses, and the coupons were carefully machined, particularly at the weld toes, to meet fatigue testing standards. For evaluation, the samples were polished before testing to ensure accurate hardness profiling across the weld zones. Comprehensive inspections, including non-destructive testing, ensured the integrity of the coupons, providing a reliable basis for the assessment of the steel's mechanical properties under cyclic loading. Welding of test coupons was executed using a standardized process to ensure the reproducibility of the results [10]. Subsequently, the coupons were subjected to fatigue testing to examine the influence of the welding on the material's fatigue strength. Particular attention was paid to the weld toe region, a known hotspot for crack initiation due to stress concentration and these coupons are illustrated in Fig. 3.

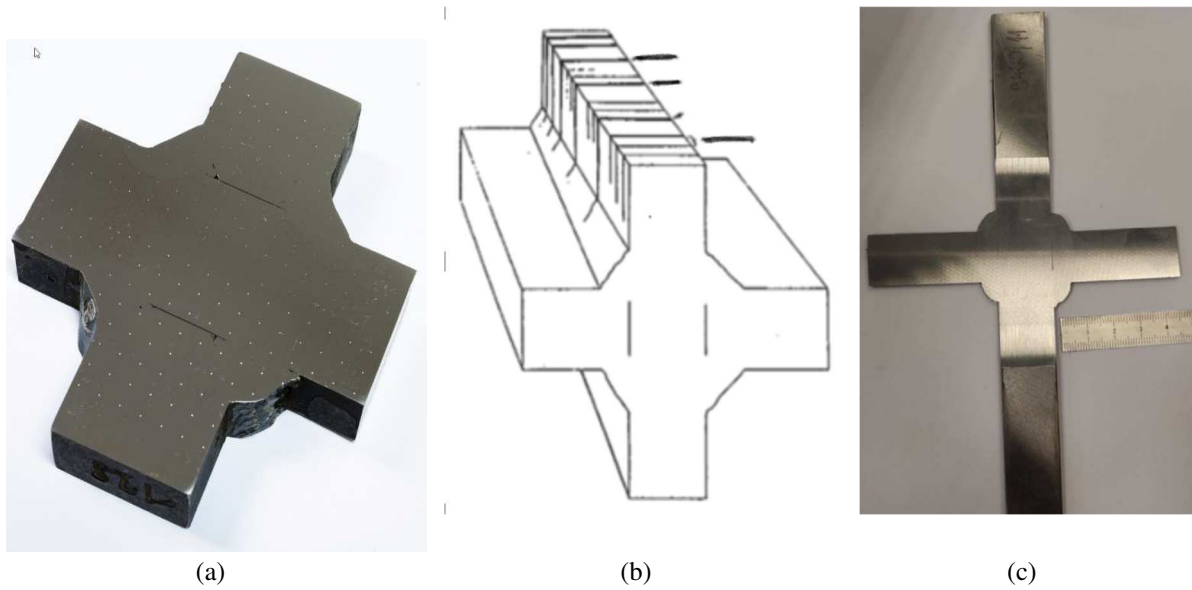


Fig. 3 Test Coupons for Study of Weld Effects. (a): Vickers Hardness Test Specimens.(b): Primary cuts: - 2 mm milling and polishing for *S-N* curves. - 10 mm milling and polishing for HV. (c): Fatigue Test Specimens.

### 3 RESULTS

The results from the Vickers hardness test revealed discernible differences between the welded zones and the base material. Specifically, the hardness values in the weld zones were consistently higher, indicating a potential increase in brittleness, which could affect the fatigue life and the results are as shown in Fig. 4 and Fig. 5.

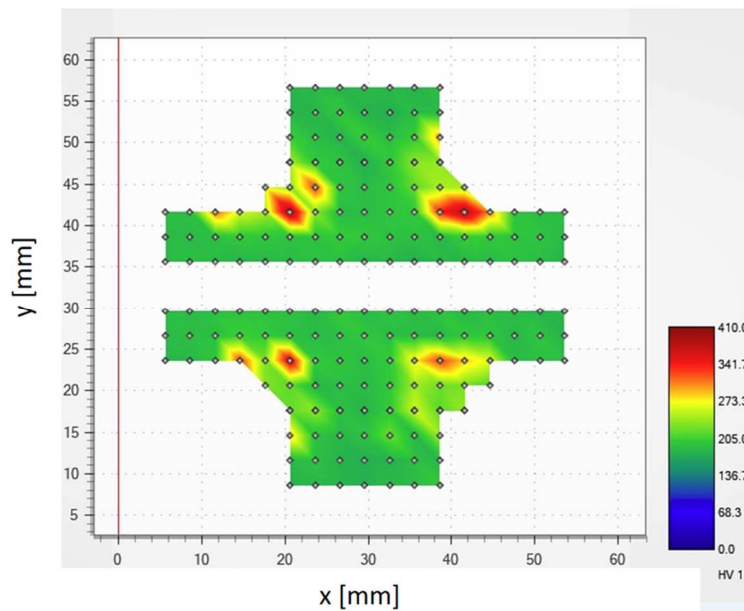


Fig. 4 Vicker Hardness Test Results for Welded Coupons (illustration).

		x [mm]															
		5.615	8.615	11.615	14.615	17.615	20.615	23.615	26.615	32.615	35.615	38.615	41.615	44.615	47.615	50.615	53.615
	5.577						183	183	196	186	188	181					
	8.577						187	186	178	185	189	180					
	11.577			A			229	193	182	183	192	193			B		
	14.577					236	244	198	184	184	200	361	234				
	17.577				229	244	422	192	182	191	200	335	234	226			
	20.577	190	193	255	225	224	277	195	178	184	201	239	238	233	194	205	186
	23.577	178	184	201	243	244	324	193	185	183	193	195	199	199	178	183	185
	26.577	193	187	193	199	207	203	185	187	185	183	186	191	182	179	183	185
y [mm]	29.577	188	191	187	181	184	188	185	186	181	178	187	199	188	186	181	185
	32.577	183	191	203	186	189	187	185	189	188	191	198	250	201	192	197	188
	35.577	189	177	191	237	264	197	188	183	186	193	353	248	275	190	190	188
	38.577	187	203	204	226	215	338	194	179	177	196	319	276	238	200	187	183
	41.577				242	239	372	194	180	180	201	237	263	270			
	44.577					233	437	199	184	186	198	416	182				
	47.577			C			264	198	182	183	190	199			D		
	50.577						189	177	181	186	187	189					
	53.577						183	180	187	187	185	183					

Fig. 5 Vicker Hardness Test Results for Welded Coupons (Map).

In the fatigue tests, the *S-N* curve for S460 steel demonstrated a typical trend, with the fatigue resistance increasing as the stress amplitude decreased. The curve was instrumental in identifying the threshold levels of stress below which the material can theoretically withstand an infinite number of load cycles. These results are particularly valuable in predicting the service life of structures utilizing S460 steel and in optimizing design for fatigue resistance. And the results are shown in Fig. 6.

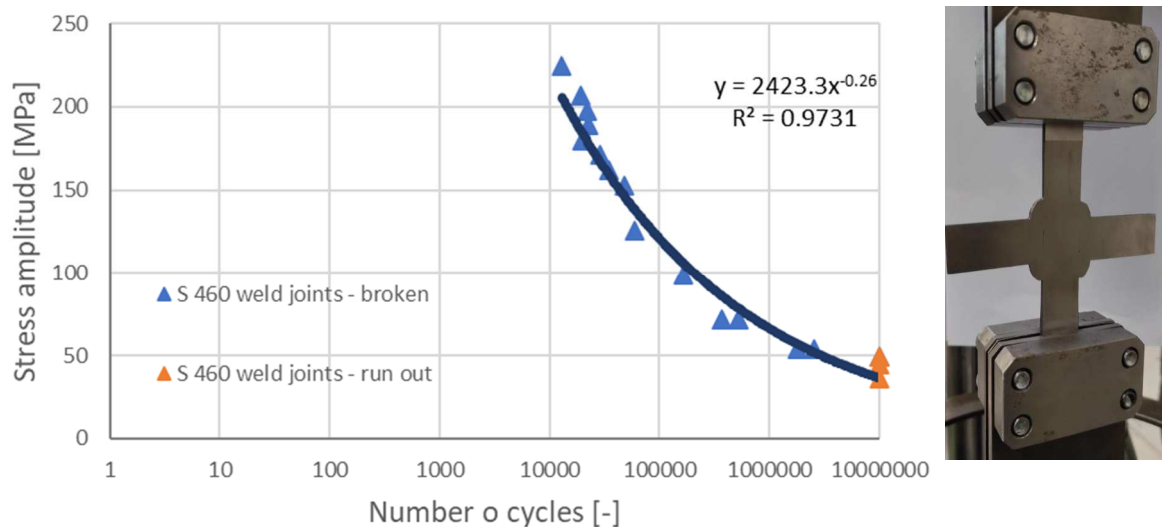


Fig. 6 Fatigue Test Results ( $R = 0.1$ ) for the Welded coupons made from S460.

The effect of welding on fatigue strength was evident from the reduced fatigue life observed in the specimens with welded joints compared to those without, as can be seen in comparing the *S-N* curves in comparison between the results in Fig. 2 and Fig. 6 or as illustrated in Fig. 7. The initiation of fatigue cracks was predominantly observed at the welded toe, corroborating the hypothesis that this zone is critical in determining the overall fatigue performance of welded structures.

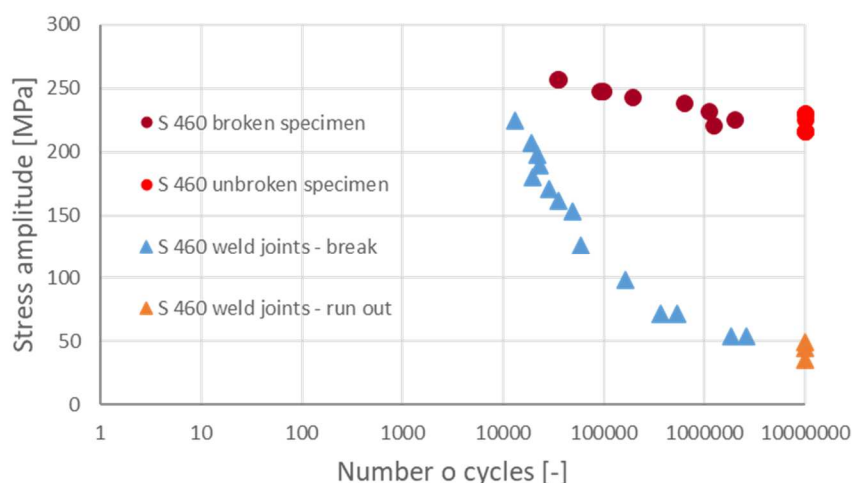


Fig. 7 Comparison between  $S-N$  curves for the original specimens and the welded ones for  $R = 0.1$ .

## 4 DISCUSSIONS

The findings from the Vickers hardness test and fatigue tests provoke a comprehensive discussion on the weld joint integrity of high-strength steel plates. The increased hardness in the welding zones suggests a microstructural transformation induced by the welding process, which is known to impact the material's ductility adversely. While higher hardness may contribute to better resistance against deformation, it also raises concerns about the increased susceptibility to brittle fracture, particularly under cyclic loading conditions.

The  $S-N$  curve portrayal of fatigue life elucidates the substantial endurance of S460 steel when subjected to low-amplitude stresses. However, in the context of welded joints, the presence of higher hardness values at the welded toe poses a challenge. The initiation of cracks in this zone is a manifestation of the complex interplay between material properties and welding-induced stresses. This reinforces the need for meticulous welding practices and post-weld treatment processes to mitigate the adverse effects and enhance the fatigue performance of the joints.

Furthermore, the study's outcomes underscore the necessity for engineers to consider these changes in material properties when designing welded structures. The use of S460 steel in construction should be accompanied by an understanding of its behaviour under various loading scenarios to ensure the safety and longevity of the infrastructure.

In comparing the  $S-N$  curves obtained from our fatigue tests on S460 steel welded coupons with those found in other literatures [11], both datasets exhibit a remarkable correlation in the trend of the fatigue life with increasing stress levels as can be seen in Fig. 8. The slope of the curves indicates a similar rate of decrease in the number of cycles to failure with increasing stress amplitude, suggesting consistent material behaviour. Notably, the endurance limits, characterized by the flattening of the curves, are comparable, reflecting the inherent fatigue resistance of S460 steel across different welding methodologies. These parallels underscore the reproducibility of our results and affirm the reliability of S460 steel in welded applications under cyclic loading.

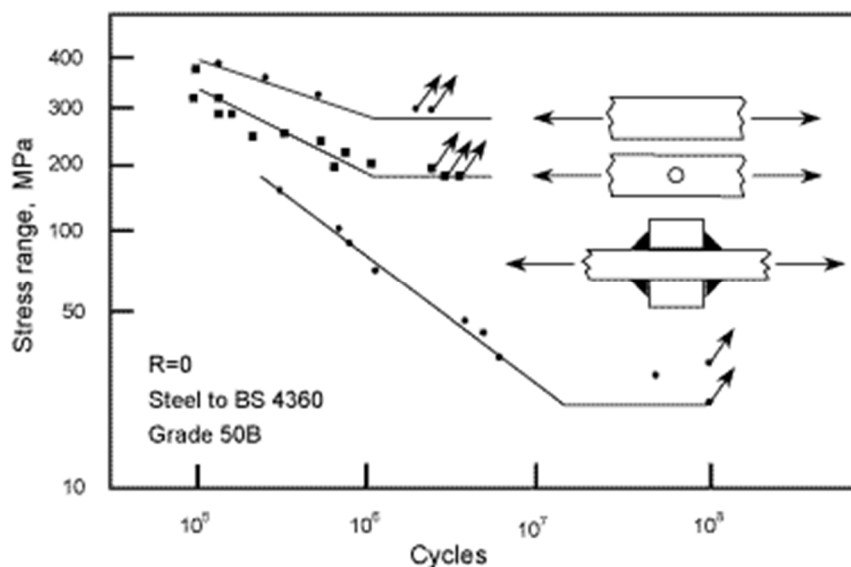


Fig. 8 Effect of welding on fatigue strength [11].

The research presents a clear indication that welding practices must be closely aligned with the material properties to guarantee the structural integrity of steel constructions. Future studies could extend this work by exploring alternative welding techniques and post-weld treatments that could ameliorate the potential negative effects observed in the weld zones.

## 5 CONCLUSIONS

The experimental analysis of S460 high-strength steel plates with cruciform weld joints has provided valuable insights into the material's behaviour under fatigue loading. The elevated hardness in the welded zones compared to the base material indicates a transformation in the microstructure due to the welding process, which could have implications for the fatigue life of the welded joints.

The study confirmed that the welded toe is a critical zone for the initiation of fatigue cracks, which is paramount to consider in the design and assessment of welded structures. The *S-N* curve analysis further demonstrated the steel's capacity to withstand high-cycle fatigue at low stress amplitudes, highlighting its suitability for use in structures subjected to such loading conditions.

In conclusion, while the use of high-strength steels like S460 offers numerous advantages in construction, the alteration of material properties at weld joints is an important factor that must be addressed. Aligning welding practices with the material characteristics is essential to ensure the longevity and safety of steel structures. Ongoing research into welding techniques and post-weld treatments will continue to play a vital role in advancing the field of structural engineering.

Future research will focus on refining welding practices and exploring post-weld treatments to enhance the fatigue resistance of welding joints. This ongoing effort to understand and improve the performance of high-strength steel in welded applications is crucial for the development of more durable and reliable infrastructures.

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