

MECHANICAL PROPERTIES OF RESISTANCE SPOT WELDED JOINTS OF MILD STEEL UNDER STATIC LOAD

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Abstract-This paper emphasizes the mechanical properties of resistance spot welded (RSW) joints of mild steel under static loading conditions. In this study, cold rolled mild steel sheets of 2 mm thickness are used. For failure analysis of RSW of mild steel joints, tensile-shear tests of the joints are conducted. The tensile-shear test is the most commonly used test for evaluating the mechanical behaviors of the spot welded joint. As the common use of the spot welded joints in automobile and aerospace industries, the mechanical behaviors of the spot welded joints under such loading conditions are an important scope to be studied. The experimental result show that the RSW joints formed under 13 KA and 4 kN can sustain 7.33 kN tensile-shear load before failure. The observation of failed specimens show that the RSW joint was failed either interfacial or plug failure mode depending on the welding parameters and welding quality. The Vickers hardness result shows that the hardness values in the weld zone of the RSW joints are about 3 times higher than that of the base metal. Such high hardness values of the weld zone is because of the martensitic formation in the weld fusion zone due to high cooling rate.

Keywords: RSW (Resistance spot welding), Mild Steel, Tensile-shear test, Hardness test, Microstructure.

1. INTRODUCTION

Resistance spot welding is the process of joining two or more metal sheets together through fusion at a certain point [1]. It is a simple process that uses two copper electrodes to press the work sheets together and force high current to pass through it. It then melts, destroying the interface between the parts. The current is switched off and the nugget of molten materials solidifies forming the joint. The growth of the weld nugget is, therefore, determined by its controlling parameters such as current, weld time, electrode tips, and force [2]. Welding is a metallurgical process—all aspects of a welding process can be, more or less, related to metallurgy of the materials involved in welding, either the base metal or the electrodes [3]. After spot welding, important changes occur in mechanical and metallurgical properties of the welded areas and heat affected zones [4]. The investigation of these changes is very important for safety and strength of the welded joints. Among such investigations mechanical properties of the joint under static load are most vital. The tensile-shear and the hardness test of the joint reveals various mechanical properties promoting the strength, crashworthiness, durability etc. [5]. Resistance welding is a highly efficient joining method that is particularly well-suited for automated production lines and mass production. Resistance welding is also suitable for small batch

production, because of its flexible method, simple equipment and ease of control over the welding process [6]. In addition, an important advantage of this method is that it can be used for joining a great number of metallic materials. This technique is commonly used in automotive, aeronautic and many other industries due to its high efficiency in joining of thin metal sheets [7, 8].

In this experiment the mechanical properties of the resistance spot welded joint of mild steel sheets were investigated under static loading conditions. The tests include tensile-shear test, the micro-hardness and the microstructure test.

2. EXPERIMENTAL

The materials used for these experiments were mild steel of 2 mm thickness, whose chemical compositions and mechanical properties are listed in Table 1.

Table 1: The Chemical Compositions and Mechanical Properties of Mild Steel

(a)						
Chemical Composition (wt%)						
	C	Fe	Mn	Cr	S	P
Mild Steel	0.12	98.91	0.63	0.29	0.03	0.02

(b)

Mechanical Properties			
	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation at fracture (%)
Mild Steel	320	165	43

For spot welding, a IT-30, 100-kVA spot welding machine was used. The welding processes were carried out under constant current and constant electrode pressure using a straight type, circular electrode tip. The machine was capable of joining various metal sheets with a thickness up to 3mm. It uses a pneumatic-based electrode actuation system to produce up to 15 kN of force, and a current range varying from 1 to 17 kA. However, in this experiment only a constant 4 kN of force and 13 kA of current was used for the entire weld schedules. The electrode tips were 8 mm in diameter. The process parameters used in this experiment are listed in Table 2.

Table 2: Specifications of resistance spot welding (RSW) process

Serial No.	Parameter	Value
1	Current	13 KA
2	Voltage	21 V
3	Average Cycle	2 sec
4	Electrode Type	Straight
5	Electrode Material	Copper
6	Shape of Electrode Tip	Circular
7	Gap in the Electrodes	70 mm
8	Electrode Tip Diameter	8 mm
9	Electrode Force	4 kN
10	Cooling Water Flow Rate	10 liter/min ~ 12 liter/min
11	Nugget Diameter	6 mm

For tensile test, two sheets of (120 mm × 40 mm × 2 mm) mild sheet specimen are spot welded in a lap joint configuration as schematically shown in Fig.1. A total 10 pairs of welded samples were fabricated for tensile-shear, micro-hardness, and microstructural tests.

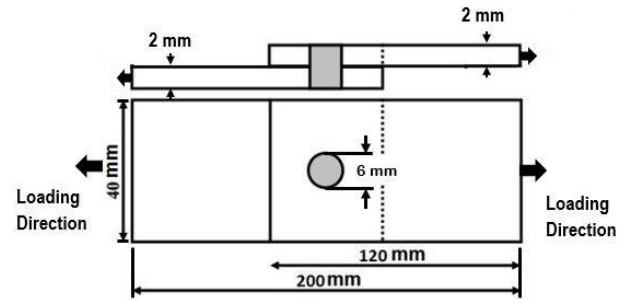


Fig.1: Geometry of the resistance spot welded joints

For the tensile-shear test, the specimens were fitted in the universal testing machine (UTM), to perform the tensile-shear test on the welded joint by applying static loads. The tests were performed at a displacement rate of 1 mm/s.

For the micro-hardness and metallurgical tests the specimens were sectioned through the weld nugget and mounted in resins using a hot mounting press, then polished thoroughly using a LaboPol-2 polishing machine to obtain a smooth surface. After mounting micro-hardness and metallurgical tests were carried out. Vickers micro-hardness test of the base metal, weld zone and heat affected zone were determined in a Vickers micro-hardness tester by applying 0.5 kgf load for 20 sec.

For microstructural investigation the mounted and polished specimen was etched in a Nital solution (2% HNO₃ and 98% C₂H₅OH) and then settled on an inverted reflected light microscope.

3. RESULTS AND DISCUSSION

After the spot weld joint each of the welded specimens was observed. As shown in Figure 2, the optical macrograph reveals that there is no visible macroscopic defect or crack observed in the welded specimen.



Fig.2: Resistance spot welded lap joints

The repeatability of the experimental results of the tensile-shear tests is reasonably good with an average maximum load to failure of 7.33 kN as listed in Table 3.

Table 3: Tensile-Shear Test Data

Test Specimen	Max. Tensile Load before Fracture
Test Specimen 1	7 kN
Test Specimen 2	7.5 kN
Test Specimen 3	7.5 kN
Average	7.33 kN

Figs.3(a) and (b) show the optical macrographs of the failed specimens. As shown in Fig.3(a) the weld zone

was failed by interfacial, whereas in Fig.3(b) the fail was initiated by necking and then the upper sheet was pull out. This type of failure was similar to the plug failure mode and generally had higher tensile load. In plug failure mode, the failure generally occurs when the joints were very strong and the base metal has residual stress or discontinuity around the weld zone. Noted that the failure mode of the welded specimens depends on the welding quality and the process parameters.

Another type of failure mode is nugget pull out. This particular type of failure did not occur in this experiment because the joints were not strong enough which might be due to the low weld current and low cooling water flow rate resulting in poor welds.



Fig.3(a): Joint failure mode: interfacial



Fig.3(b): Plug failure mode

The micro-hardness results are shown in Fig.4. As shown in Fig.4, the micro-hardness of the base metal is about 225 HV (avg.) and the micro-hardness of the weld zone is about 815 HV (avg.). The micro-hardness values in the nugget zone were considerably higher than that of the base metal, which is due to microstructural change in fusion region. A more clear understanding of such high values of micro-hardness can be described from the microstructural change in the fusion zone.

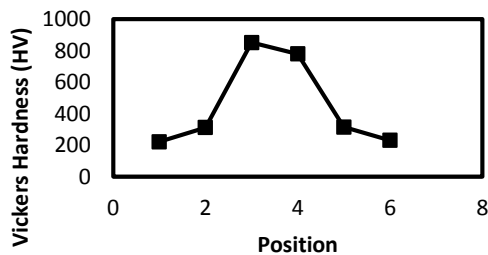


Fig.4: Micro-hardness data plot with respect to position

Figures 5(a) and (b) show the microstructure of the base metal and weld zone, respectively. As shown in Figure 5(a), the microstructure of base metal is mostly ferritic

with a small amount of Fe_3C structure. On the other hand, the microstructure of weld zone shows martensitic structure (Fig.5(b)). The martensitic phase transformation was due to high cooling rate during RSW process. The microstructure observed in the base metal are more of a coarse grain microstructure (Fig.5(a)), while the microstructure of the weld zone consists of much finer grain microstructure. Noted that weld zone microstructure of the resistance spot welded joints of low carbon steel depends on the chemical compositions of the sheet and cooling rate during the welding process. High cooling rate of the RSW process can explain martensitic formation in the weld nugget of mild steel. Which is also responsible for the higher hardness values in the weld zone than the base metal and the heat affected zone.

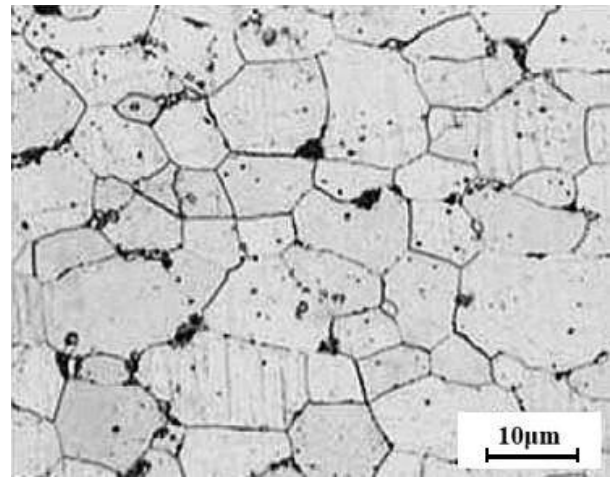


Fig.5(a): Microstructure of base metal

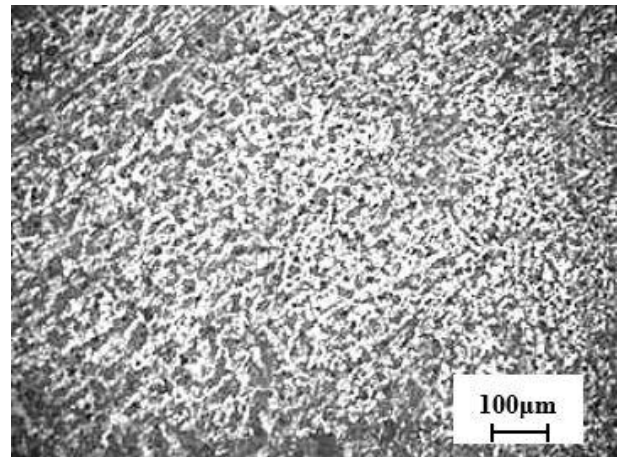


Fig.5(b): Microstructure of fused zone.

4. CONCLUSION

The tensile-shear test results show that the average tensile-shear strength of the resistance spot weld joint is 7.33 kN which is one third (1/3) of the tensile strength of the base metal.

The micro-hardness test results of the specimen yields that the hardness increases along the line from the base metal through the heat affected zone to the fused zone. From the data collected during micro-hardness test it is evident that the hardness of the fused zone of resistance

spot welded joint increased about 3 times the hardness of the base metal.

The metallographic investigation revealed a subsequent amount of martensitic formation in the fused zone is due the quenching effect of the instant cooling during the welding process. The microstructures of the specimen shows a grain size transition from the base metal to the fusion zone. It is clear that, the heating and instant cooling during welding process, refined the grain structure in the fusion zone.

5. ACKNOWLEDGEMENT

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