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Comparing the mechanical and expected microstructural properties of (TIG) spot welding and resistance spot welding in automobile body restoration

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مقارنة الخصائص الميكانيكية والبنية المجهرية المتوقعة للحام النقطي (*TIG*) ولحام المقاومة النقطي في ترميم هياكل السيارات

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Abstract:
Resistance spot welding is widely used in automobile industries due to its low cost, quality, and ease of implementation. In spite of that, the process often faces limitations related to the accessibility and variations in joint strength relative to the original manufacturing when performing restoration. The purpose of this study is to overcome these difficulties by comparing the mechanical and expected microstructural properties of TIG spot welding to offer a good alternative. This comparison includes peel testing, tensile testing, shear testing, and hardness testing. The results showed the welded dimensional nugget size is comparable to that produced by resistance spot welding, and TIG-spot welded samples showed a lower hardness but a higher tensile and shear strength. These results suggest future optimization of the parameters to achieve accurate weld spot sizes comparable to resistance spot nugget size or implant the same processes in an automated TIG welding machine.

Keywords: Welding, TIG-spot, Microstructural, Resistance, Automobile, Nugget.

الملخص
يستخدم لحام المقاومة النقطي على نطاق واسع في صناعة السيارات نظرًا لانخفاض تكلفته وجودته وسهولة تنفيذه. ومع ذلك، غالبًا ما تواجه هذه العملية قيودًا تتعلق بسهولة الوصول واختلافات قوة الوصلة عند إجراء عمليات الترميم مقارنةً بقوتها عند التصنيع. تهدف هذه الدراسة إلى التغلب على هذه الصعوبات من خلال مقارنة الخصائص الميكانيكية والبنية المجهرية المتوقعة للحام النقطي اليدوي بتقنية TIG، وذلك لتقديم بديل مناسب. تشمل هذه المقارنة اختبارات التقشير والشد والقص والصلابة. أظهرت النتائج أن حجم بقعة اللحام النقطي TIG يُضاهي حجم بقعة اللحام الناتجة عن لحام المقاومة النقطي، وأن عينات اللحام النقطي TIG أظهرت صلابة أقل ولكن قوة شد وقص أعلى. تشير هذه النتائج إلى ضرورة تحسين مدخلات اللحام مستقبلًا للحصول على أحجام أصغر لبقعة اللحام كي تضاهي أحجام بقعة اللحام الناتجة عن لحام المقاومة النقطي، أو استخدام آلات تُؤدي نفس العملية في أنظمة لحام TIG الآلية.

الكلمات المفتاحية: اللحام، TIG النقطي، البنية المجهرية، لحام المقاومة، السيارات، بقعة اللحام.

Introduction

Welding is a fundamental technology in the production and repair of metal products, especially in the automotive industry. As automobiles continue to dominate the global transportation sector, the demand for sustainable and efficient welding processes is growing [1]. resistance spot welding is known as high strength, high productivity, and low cost, which is one of the most popular welding techniques in the automotive industry. A single car may consist of 5,000 to 20,000 spot welds. Electronics, railroads, aircraft, and home appliance production use resistance spot welding. And contributed to automotive accident repair widely used despite some limitations. In some cases of automobile body repairs, two-way contact with materials is required, which is often difficult and challenging. The process often faces limitations related to the accessibility, thermal deformation, and variations in joint strength relative to the initial manufacturing. To overcome these difficulties while maintaining the required mechanical properties and microstructure, alternative welding methods are needed [2]. Tungsten inert gas (TIG) welding, including plug welding and spot welding, offers a good solution. TIG welding is an excellent repair option for single-sided welding when double-sided is not possible. The repair can be done by drilling a hole in the top plate at the joint location and then the filler metal required for plug welding [3]. TIG spot welding simplifies the process by reducing heat and is employed without the need for applying contact pressure on both sides of the metal sheet. These methods are particularly suitable for thin metal sheets because they are flexible, economical, and easy to handle. In recent years, studies of TIG spot welding and RSW have increased. Due to its high joint strength, high efficiency, and compatibility with robotic systems, RSW has become the most popular welding technology in the automotive industry. However, comparative studies on the mechanical properties and microstructural characteristics of TIG spot welding and RSW remain limited in the specific area of automotive body repair. Resistance spot welding (RSW) is known for its superior efficiency and joint strength, while TIG spot welding overcomes space limitations and simplifies maintenance [4]. Since RSW is considered an economic method, it will continue to dominate and still be preferred by the majority of the automotive industry [3]. TIG spot welding often produces a wider heat-affected zone (HAZ) compared with RSW. Researchers have addressed that a proper parameter can produce nugget sizes that can be comparable. This is helpful in repair scenarios when accuracy and accessibility are essential. In welding, hardness and microstructure are closely connected. During TIG welding, softening of the subcritical heat-affected zone comes with a significant martensitic tempering, while this phenomenon is not observed in resistance spot welding. Due to the difference in microstructure, the hardness of the TIG spot-welded joint is slightly lower than that of resistance spot welding. However, according to standards, the joint strength is sufficient to meet application requirements [2].

The purpose of this study is to determine whether TIG spot welding is a very effective and reliable method for repairing cars. by analyzing its joint strength and weld quality compared to resistance spot welding (RSW).

Material and methods

This study investigated the differences in mechanical and expected microstructural properties between resistance spot welding (RSW) and TIG spot welding on 1 mm thick steel sheets (between 0.6 and 2.0 mm thick), commonly used in automotive body parts.

Table 1. Nominal Chemical Composition of the base metals.

C%	Mn%	Si%	P%	Cr%	Ni%
0.210	0.442	0.159	0.028	0.021	0.026
Co%	W%	Ce%	Cu%	Al%	Fe%
0.004	0.038	0.058	0.057	< 0.001	98.736

The testing procedures for both welding processes start with the preparation of five welds for each mechanical test, three welds for the hardness test, and five welds for the metallographic analysis. Table (1) shows the chemical composition of the steel used, which is low carbon steel grade AISI 1020. Steel plates were cut into dimensional of 100 mm × 25 mm. The first set of plates was welded using an ESAB TECNA ARM 4623N resistance welding machine at a power of 82 kVA and a frequency of 50 Hz, producing weld nuggets of about 4 mm in diameter, as shown in the figure (2). The second set of TIG spot-welding plates was welded by a Miller Dynasty 400. The welded nugget size was about 6 mm, as shown in the figure (3) which is comparable to that produced by resistance spot welding. Tensile shear, and peel tests were performed by placed one over the other at the ends to form a lab weld specimen as shown in the figure (1).

Figure 1: lab weld specimen.

The welding parameters used for resistance spot welding are as illustrated in the table (2), and spot TIG welding in the table (3).

Table 2. Resistance Spot Welding control parameters.

Squeeze (cycle)	Weld time (cycle)	Current (KA)	Hold Time (cycle)	Electrode diameter (mm)	Electrode force (Mpa)
40	3	9.2	20	7	0.35

Table 3. Spot TIG Welding control parameters.

Current type	Amperage	Shielding gas	Electrode type	Electrode diameter (mm)	Nozzle diameter (mm)	Gas flow rate (lit/min)	Arc duration (s)
DC	115	Ar	E WTh-2	2.4	9	10	2.15

Figure 2: resistance spot Welding measurement.

Figure 3: TIG Spot Welding measurement .

Results and discussion

TIG spot welding is done manually and without any fixture to match actual welding processes in workshops. In contrast, resistance spot welding, electrodes apply a pressure and used as a clamp which should be considered in the overall assessment.

Peel test

In this method, one side of a sheet is peeled away from the other, which promotes failure in the heat-affected zone (HAZ). The result of one side load concentration leads to failure differently [5]. All specimens fractured in the base metal as shown in the figure (4&5). Since the weld strength is higher than that of the base material, this failure is Acceptable according to ASME IX QW-196.2.2.

Figure 4: Peel test for spot TIG welding.

Figure 5: peel test for resistance spot welding.

Tensile shear tests and U-shaped tensile tests Results.

The specimens were prepared in accordance with ASME standard QW-462.9, and tested as shown in the figure (6).

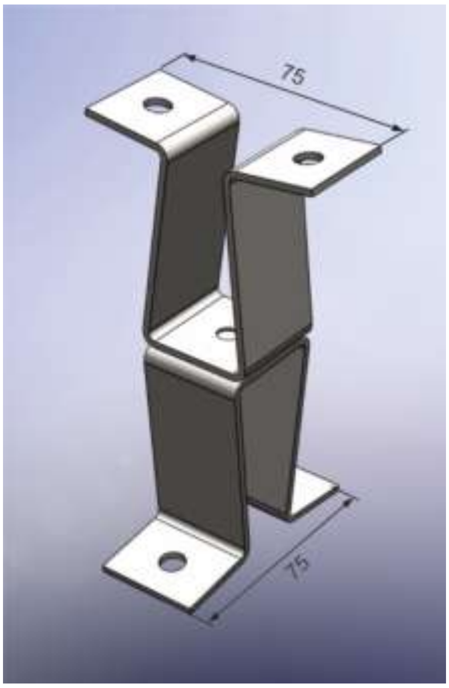

Figure 6: U tensile test.

For the evaluation weld strength of TIG Spot welding and Resistance Spot Welding (RSW). The following formula was applied to determine the results as shown in the table (4) and (5).

$$strength = \frac{\text{load to failure}}{\text{area of the nugget}}$$

The nugget's area is equal to π × d2/4, where d is the spot's minimum diameter.

TIG spot welding in the shear tensile test showed the higher average load failure with 6.496 KN compared to resistance spot welding with 4.577 KN.

Table 4 Spot Welded Samples: Shear Test Results**.**

Sample No	Load to failure (KN)	Shear (KN/mm2)
1	6.474	0.515
2	4.462	0.355
3	4.253	0.389
4	3.908	0.311
5	3.790	0.302

Table 5 TIG Spot Welded Samples: Shear Test Results.

Sample No	Load to failure (KN)	Shear (kN/mm2)
1	6.599	0.525
2	6.591	0.524
3	6.488	0.516
4	6.457	0.514
5	6.347	0.505

Meanwhile, the obtained results illustrate an average load of 1.382 KN for TIG spot welding, which is slightly higher compared to an average load of 1.226 KN for resistance spot welding as shown in the table (6) and (7).

Table 6 Spot Welded Samples: Tensile Test Results**.**

Sample No	Tensile (KN)	Average load (KN)
1	1.357	1.226
2	1.298	
3	1.196	
4	1.141	
5	1.136	

Table 7 TIG Spot Welded Samples: Tensile Test Results.

Sample No	Tensile (kN)	Average load (KN)
1	1.529	1.382
2	1.443	
3	1.414	
4	1.261	
5	1.261	

Hardness test

There was a significant increase in hardness from 70 to 94.76 on average in resistance spot welding. While the average result of TIG spot welding showed a significant decrease in hardness from 70 to 43.85, as shown in the table (8) and (9).

Table 8 spot weld: hardness test results (Rockwell HRB)

Sample No.	Base metal	Weld metal			Average
S1	70	**85.5**	**92.6**	**103.4**	93.83
S2		**81.6**	**94.5**	**100.9**	92.33
S3		**106.9**	**83.2**	**104.5**	98.2

Table 9 TIG Spot weld: Hardness test results (Rockwell HRB)

Weld metal	Average	Sample No.	Base metal	Weld metal	Average
T1	70	**47.1**	**34**	**45**	42.03
T2		**51.7**	**33.5**	**30.6**	38.6
T3		**48.8**	**52.9**	**49.4**	50.36

In general, the differences in tensile strength, shear strength, and hardness between TIG spot welding and resistance spot-welded samples are governed by heat input, cooling rate, weld geometry, and resulting microstructural transformations.

TIG welds exhibit lower hardness but have higher tensile and shear strength. This can be attributed to changes in microstructure due to the different cooling rates. TIG spot-welded samples have a lower cooling rate, and this led to a wider fusion zone and more uniformity, resulting in less stress concentration and better load distribution during tensile and shear. There arrangement of grains exhibited the TIG spot welded samples more strength in the direction of tensile test axis and less hardness in hardness test.

Spot-welded samples showed higher hardness but lower tensile and shear strength. This behaviour can be attributed to the highly hardened microstructure (martensite) in the weld nugget. This microstructure is hard but brittle and susceptible to crack initiation and interfacial failure. And this explains why the spot-welded samples showed higher hardness but less strength under tensile and shear loads.

Conclusion

According to the result analysis, the hardness and peel testing are logical compared to previous researches and match the principle physical welding result.

0n the other hand, The Mechanical Strength (Shear/Tensile) Results: In TIG Spot Welding, these results are logical and acceptable, especially since the higher shear strength may be related to increased ductility resulting from softening, or to the size of the weld nugget.

Despite TIG spot welding being performed manually, which tends to increase the possibility of differences in results between samples, this does not disprove the logic of the total results, particularly regarding hardness and strength.

The results are technically logical and consistent with the microstructure changes in the hardness, while the mechanical strength results are still within the range of possible results depending on the specified welding parameters.

Overall, and according to the finding, the suggestion is that a future study should aim to optimise the parameters to achieve accurate weld spot sizes or implement the same processes in an automated TIG welding machine.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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