

Effects of Surface Treatment on Strength And Hardness of Aluminum Alloy/ Galvanised Steel Resistant Spot Weld-Zn Coated Single Lap Joint

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ABSTRACT

In manufacturing, joining dissimilar metals is a crucial challenge. This study looked into the lap joining of galvanised steel to aluminum sheets (AA5052) using different materials by using a spraying technique to introduce a zinc conductive interlayer. Therefore an experimental investigation into the effects of alkaline treatment was conducted using potassium permanganate (KMnO₄) and hydrogen peroxide (H₂O₂) at different immersion times (0, 10, 20 and 30 minutes). Zinc-rich layer was applied to the treated samples and single lap joints were welded using resistance spot welding (RSW) at 7 kA for 5 seconds. The resulting treated samples underwent comprehensive characterisation using several techniques, including macroscopic observation, surface roughness, nugget size measurement, tensile test, Vicker microhardness, pH measurement, and conductivity test. The results indicated that KMnO₄ exhibited a higher etching rate and greater material removal during the chemical treatment than to H₂O₂. This resulted in the breakdown of the oxide layer on the metal surface, yielding increased surface roughness and improved conductivity for galvanised steel and AA5052 treated with KMnO₄. The pH of the treated sample rose with prolonged immersion time, with KMnO₄ exhibiting a higher pH value (9.48) compared to H₂O₂ (3.80) at the optimal immersion duration of 30 minutes. This condition resulted in an increased heat input, potentially enlarging the weld nugget diameter and thereby significantly enhancing both weld strength and hardness.

Keywords: Spot weld; alkaline treatment; dissimilar metals; zinc interlayer

INTRODUCTION

The automotive sectors have become more competitive recently. Less petrol consumption is one of the qualities sought for in the automotive sector. Automobile manufacturers thus often cut the overall weight of the vehicle to lower energy consumption. Therefore, reaching this specification depends much on lightweight vehicles. Aluminium (Al) and its alloys have gained popularity as a material of choice for automakers in producing less-energy-consuming vehicles. The reason for the choice of aluminium and its alloys include high strength-to-weight ratio, high corrosion resistance and high malleability (Amanollahi et al. 2021; Zhang et al. 2024). However, there

are some sections of automobiles such as frame, chassis and axles where extremely high toughness, tensile and impact strength are required. Alloy steels such as galvanised steel is currently being utilised for this purpose. Thus, there is a necessity for dissimilar welding of steels and aluminium alloys to attain an equilibrium between cost and mechanical performance in automobiles. This method of dissimilar joining aluminium and galvanised steel is a cost-effective means of decreasing vehicle weight without compromising automotive performance.

Resistant spot welding (RSW) is the most dominant process in sheet metal joining which has been mostly employed to assemble similar or dissimilar metals in welding of car bodies. The RSW technique have been

extensively applied due to its repeatability, low-cost equipment, lower skill requirement for operation and for welding of numerous metals such as steel, aluminium (Al), magnesium (Mg), titanium (Ti) and their alloys (Das & Paul 2021; Bhuyan et al. 2024; Vigneshkumar et al. 2021; Manladan et al. 2017). Although the joining by RSW is a promising method, however, dissimilar welding of aluminium alloy-galvanised steel is extremely a challenging task due to the wide variation in thermal properties, presence of oxide layer and development of intermetallic compound (IMC) at the interfacial area (Das et al. 2019; Neystani et al. 2019). The presence of thin aluminium oxide (Al_2O_3) layer that is formed naturally on aluminium surface is beneficial in protecting the base metal from corrosion however, it is detrimental to welding. The melting temperature of Al_2O_3 (2060 °C) is relatively higher than the parent aluminium alloys (660 °C). Galvanised coating, like aluminium alloy, provides barrier protection to steel by forming zinc oxide (ZnO) on its surface. During welding, the oxide layer on the molten pool can cause fusion defects and porosities, reducing weld strength. Specifically, Sigler & Carlson (2018) observed that the development of RSW process for the joining of aluminium to steel produced oxide film that are rich in oxygen and magnesium, resulting in the formation of microcracks. Hu et al. (2021) also demonstrated that the oxide film structure in aluminium-steel RSW showed low-energy crack path that could negatively affect weld mechanical properties.

During the RSW process, the oxide layer increases the resistance of conductivity in both dissimilar metals, resulting in an increase in the required welding current. Furthermore, the formation of an intermetallic compound (IMC) layer at the faying interface as a result of the reaction between aluminium alloy and galvanised steel degrades weld joint quality (Pouranvari 2017). In order to increase the weldability between aluminium alloy and galvanised steel, it is necessary to remove the surface oxide prior to welding to enhance the performance of weld joint (Iqbal 2019). In another study, Al-Naimi et al. (2015) investigated the influence of pre-treatment using NaOH and glass blasting in RSW of AA1050 sheets with different thickness (0.6 mm, 1.0 mm and 1.5 mm). They found that thicker oxide layer showed higher electrical contact resistance and the highest strength were obtained by pickling in NaOH due to the highest removal of oxide layer. In another study conducted by Gáspár et al. (2021), they used NaOH followed by mixture of HNO_3 and HF to remove the oxide of AA7075. Ronnhult et al. (1980) have studied the effect of the surface condition on the RSW of AA5252 by comparing the weldability of the as-received specimens with that of the specimens pickled in NaOH and oxalic acid. They recommended an excellent weldability can be achieved by removing the oxide layer through pickling.

Meanwhile, Zedan & Doos (2018) removed the oxide layer for dissimilar 1008 low carbon steel-AA5052 by using abrasive paper.

Although different techniques and materials were investigated by these researchers, however, studies assessing the relationship between the surfaces after treatment and the weldability of dissimilar metals are still relatively rare. Therefore, the present work aimed to investigate the role of surface treatment in RSW of the aluminium alloy (AA5052) to galvanised steel through comparison of mechanical properties of the RSW joints. For this consideration, the metal surface preparation was performed including chemical treatment and mechanical cleaning (grinding) as these approaches were among the methods that was considerably appropriate to remove the oxide layer.

METHODOLOGY

The workpieces were made of an aluminium alloy (AA5052) and galvanised steel with a constant thickness of 0.6 mm. The sheet metal was cut into dimensions of $200 \times 25 \times 0.6$ mm with a foot shear cut machine. Figure 1 shows how a lap joint was used to join AA5052 and galvanised steel. Each condition in the experimental work was represented by three sets of samples.

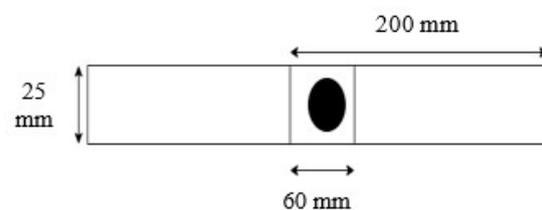


FIGURE 1. Sample dimension

The samples were degreased using acetone to prepare them before welding. To eliminate surface scratches, the samples were ground on 80-grit silicon carbide (SiC) papers then cleaned with acetone. Two kinds of chemicals, hydrogen peroxide (H_2O_2) and potassium permanganate (KMnO_4), with varying immersion times (0, 10, 20 and 30 minutes) were applied on the surface of the AA5052 in order to investigate the effect of different chemical treatments. Usually, the surface treatment is completed on both sides of galvanised steel and AA5052. Furthermore applied on the outer sides touching the electrode was zinc interlayer using a spraying technique. Applying the zinc layer helps to avoid a direct contact between AA5052 and galvanised steel. Moreover, the inclusion of zinc as a conductive material may diminish the requirement for

elevated welding current during the penetration of a metal spot designated for welding. Following surface treatment, all samples were sprayed from a constant distance of 30 cm with zinc coating dry film known as crown cold galvanised coating (93% zinc rich) supplied by Aervoe Industries. The coating layer was left to dry for 15 mins. Subsequently, the samples were welded in single lap joints using RSW machine (Digital Spotter 9000). The welding power and welding cycle was set at 7 kA and 5s, respectively. Table 1 shows the welding machine specifications.

Following welding, the changes in nugget size were measured and recorded. To evaluate the strength of the welded region, tensile shear strength was measured using a Universal Tensile Test Machine. The speed and maximum force were 1.3 mm/min and 50 kN, respectively. The Vickers microhardness test was performed on the Mitutoyo HM-200 to determine the hardness of various welded zones, including the fusion zone, heat affected zone, and base metal. The load used and dwell time for each of the indents were 0.3 kgf and 10 s, respectively. The roughness was measured using a Mitutoyo SURFTEST SJ-410 after various chemical etching treatments with different immersion times. The pH values of H_2O_2 and $KMnO_4$ were measured before and after treatment with a HANNA benchtop pH meter. Finally, the conductivity was measured with an Agilent Digital Multimeter.

TABLE 1. Welding machine specification

Model	Digital Spotter 9000
Main voltage	400V, 2 Phase
Max spot-welding current	7000A
Max no load voltage	8.6V
Max absorbed power	40kW
Rated power X=50%	13kW
Power factor	0.7cosphi
Max welding thickness on 2 sheets	3+3 mm
Duty cycle	3%
Dimension (LxWxH)	760x540x1080mm
Weight	82kg

RESULTS AND DISCUSSION

MACROSCOPIC OBSERVATION

Figure 2 depicts the colour changes in the metal surfaces of AA5052 and galvanised steel before and after surface treatment. $KMnO_4$ and H_2O_2 are known oxidising agents. Following surface treatment with $KMnO_4$ and H_2O_2 , the colour of both dissimilar metal sheets changed slightly.

AA5052 is prone to corrosion. Its exposure to chemical treatment therefore only produced a minor surface discolouration. Unlike AA5052, the surface colour of galvanised steel changed to light golden brown, which especially matched the iron oxidation so-called rust. When the sheet metals were exposed to the extreme chemical solution, the natural protective aluminium oxide (Al_2O_3) layer that was formed on the surface of aluminium alloy and a thin barrier layer of zinc oxide (ZnO) on the surface of galvanised steel were chemically deteriorated (Hamid et al. 2010; Fusco et al. 2019). As a result, the oxide layers become unstable and degrade locally, resulting in the oxide layer breakdown. $KMnO_4$ had a higher oxidising power than H_2O_2 . This current situation indicated that $KMnO_4$ had a higher pH, which aided in the destruction of the oxide layer on metal surfaces. This condition implied that the different colour changes on the two dissimilar metal sheets after the surface treatment were strongly related to the oxide layer behaviour.

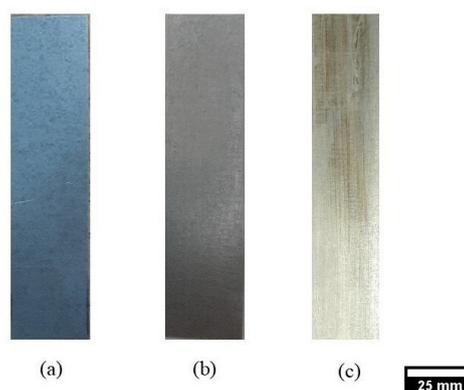


FIGURE 2. The macroscopic appearances of galvanised steel: (a) before immersion process, (b) after immersion in H_2O_2 for 30 mins, and (c) after immersion in $KMnO_4$ for 30 mins

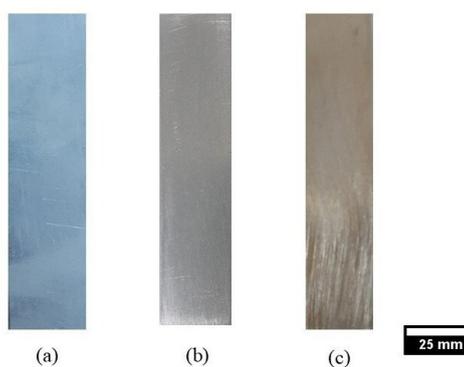


FIGURE 3. The macroscopic appearances of AA5052: (a) before immersion process, (b) after immersion in H_2O_2 for 30 mins, and (c) after immersion in $KMnO_4$ for 30 mins

SURFACE ROUGHNESS

Surface roughness is effective in breaking down the contact resistance at the faying surface when the material has a thin and insulating layer. The contact resistance at the faying surface was critical since the nugget formation was initiated here during welding. Surface roughness test was carried out to determine the grade of roughness of metal surface as result of different chemical treatment (KMnO_4 and H_2O_2) and various immersion times of 0, 10, 20 and 30 mins, as shown in Figure 4. The surface roughness caused by the chemical treatment increased with increasing immersion time. Galvanised steel immersed in KMnO_4 had a higher surface roughness than H_2O_2 . The galvanised steel immersed in KMnO_4 for 30 minutes had the highest surface roughness (0.554 Ra) of any sample tested. The surface roughness of the untreated galvanised steel (shown by 0 min immersion time) displayed the lowest surface

roughness (0.363 Ra) comparatively. This means that surface roughness increased as a result of the chemical treatments. This indicates that the surface treatment helped to improve surface protection.

As the aluminium oxide layer was amorphous and porous, thus immersing the sheet metals in the alkaline solution might contribute to a significant change in their structure (Milinchuk et al. 2019). Figure 5 shows that the non-immersed AA5052 had the lowest surface roughness (0.644 Ra). Surface roughness increased dramatically as the immersion time increased from 0 to 20 mins. However, slight increase in the surface roughness was observed when the immersion time increased from 20 to 30 min. Generally, increasing the immersion time tends to increase the oxide dissolution rate and dissolved area of the aluminium alloy (Ng et al. 2014). The aluminium surface became rougher as the immersion time increased. As a result, the rougher surface led to the breakdown of the oxide layer.

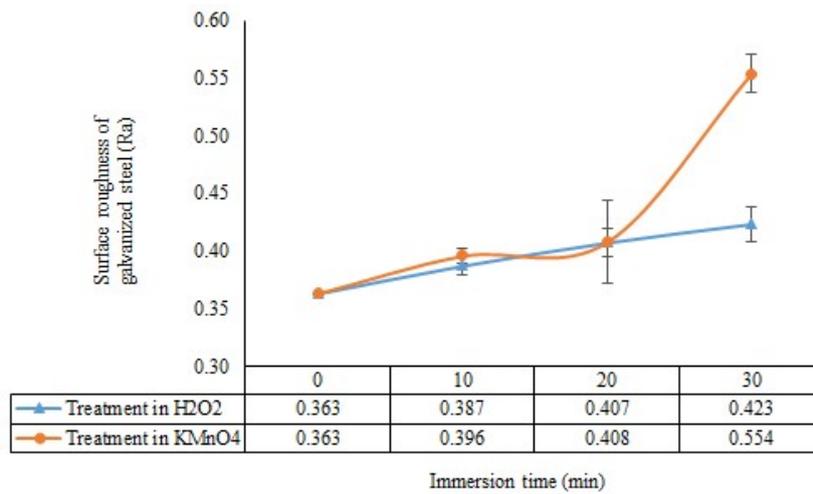


FIGURE 4. Surface roughness of galvanized steel immersed in H_2O_2 and KMnO_4 for various immersion time

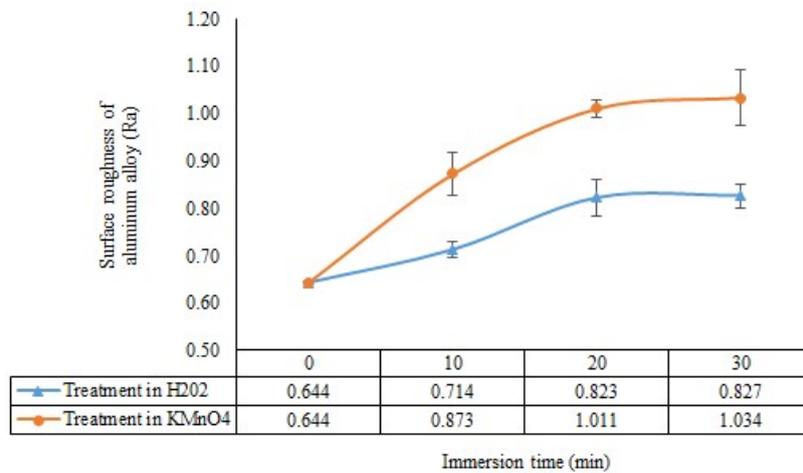


FIGURE 5. Surface roughness of AA5052 immersed in H_2O_2 and KMnO_4 with various immersion time

A chemical treatment by KMnO_4 showed an enhancement in promoting higher surface roughness than H_2O_2 . This finding was in line with a study conducted by Arsyad & Soenoko (2018) who found that higher concentrations of KMnO_4 gave higher grades of surface roughness. This result indicated that KMnO_4 had a higher etching rate because it contained a stronger oxidising agent (high pH), which was responsible for the removal of the oxide layer. The oxidising agent acted as a source of hydroxyl radicals ($\text{OH}\cdot$). During the chemical treatment, $\text{OH}\cdot$ from oxidising agent reacted with the oxide layer on the metal surface and facilitated the hydrogen evolution which was then immediately etched away the oxide layer from the metal surface (Michał & Gregory 2019; Thomas et al. 2024). The addition of stronger oxidising agent (with high pH) led to the higher etching rate and higher breakdown of the oxide layer, thus resulted in higher surface roughness (Doos et al. 2013). Meanwhile, the lower surface roughness in H_2O_2 cause poor removal of oxide layer in which this oxide layer acted as an insulator on the contact surface. This situation prevented metal-to-metal contact, thus increased the electrical resistance that led to a formation of smaller weld nugget. The removal of oxide was particularly important because it acted as an insulator, potentially resulting in incomplete penetration during welding.

Surface roughness shown by AA5052 exceeded that of galvanised steel. Natural oxide layer developed immediately on the aluminium substrate during air exposure due to its great affinity to oxygen, so remarkably shielding the substrate from additional oxidation. However, the addition of oxidising agent led to the formation of hydrogen gas that can facilitate a detachment of the oxide layer on aluminium surface, thus increased the surface roughness (Li et al. 2017). The oxidation kinetics of aluminium can be altered by surface roughness in which the aggressive ions might penetrate into the oxide layer and responsible for the layer breakdown that hindered the repassivation step.

NUGGET SIZE MEASUREMENT

The formation of weld nugget is a balance between heat generation and heat dissipation during spot weld. The final nugget size was considerably acquired at the end of cooling time as within the cooling stage, there was a deformation in the welding zone of the weldment which was due to the electrode pressure and material shrinkage. The nugget size of the sample consisting of dissimilar joints between AA5052 and galvanised steel was measured. The nugget size of the sample as a function of increasing immersion

time in H_2O_2 and KMnO_4 is shown in Figure 6. The nugget size rose in line with the rising immersion time. The largest of nugget size (0.723 mm) was obtained at the immersion time of 30 minutes when surface treatment was performed by submerging the sample into H_2O_2 . The maximum nugget diameter among the studied samples was obtained by immersing the sample in KMnO_4 for 30 mins (0.860 mm).

Noticeably, the nugget diameter in the welded region of sample immersed in KMnO_4 was higher than sample immersed in H_2O_2 . This can be attributed to the higher removal of the oxide layer on the metal's surfaces. As a result, by applying electrode force to the surface treated sheets, the heat generated in a localised area tended to raise the contact surface temperature, allowing the contact zone to melt and be joined with pressure. Therefore, the rise in heat input connected with the nugget's size influenced the joint strength by means of their effect. This aligns with a study conducted by Stefan et al. (2019), who investigated the influence of surface layers on resistance spot welding for Al alloys 5182 and 6016. They reported that the oxide layer on Al surfaces leads to high contact resistance between the sheet metal and the electrode. Hence, breaking this insulating oxide layer can improve the weld quality. This finding is consistent with previous studies reported by Rashid et al. (2010), who also suggested that the removal of the oxide layer is essential for successful spot welding, as current can flow through the interfaces only when the oxide layer is disrupted, allowing metal-to-metal contact. Meanwhile, as the electrical current was applied to the oxide layer (non-conductive layer) at the faying surfaces, the partial current passed through the previously created weld, so reducing the weld nugget size.

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TENSILE TEST

The size of the weld nugget at the metal sheet interface helped to define the mechanical strength of spot weld.

Higher load-bearing capacity provided by larger diameter weld nuggets would thus help to raise the weld strength. This situation revealed a rather correlated relationship between the joint's nugget diameter and the weld strength. The load was transferred by the weld nugget, which also could influence RSW joint failure mode.

Figure 7 shows effects of chemical treatment using $KMnO_4$ and H_2O_2 within various immersion times on the tensile properties of the dissimilar metal joints of the AA5052 and to the galvanised steel by RSW. According to the immersion in H_2O_2 , the highest tensile strength (175.73 N/mm^2) was achieved by immersing the sample for 30 mins. Sample submerged in $KMnO_4$ for 30 minutes (299.60 N/mm^2) had the highest tensile strength among the tested specimens. Meantime, the untreated sample showed the lowest tensile strength (90.04 N/mm^2). This phenomenon indicated that increasing immersion time increased the tensile strength of the joint samples. The contact of untreated metal surface sample with the electrodes resulted in a reduction of the tensile strength. This condition explained that the surface treatment improved the welding quality as compared to the as-received surface condition. According to these findings, the welded sample immersed in $KMnO_4$ possessed significantly higher mechanical strength than the sample immersed in H_2O_2 . The reason for this phenomenon was the increased surface roughness caused by $KMnO_4$, which resulted in the insulated oxide layer breaking more frequently. Therefore, the application of electrode force during welding resulted in increased heat

generation as a result of the lower electrical contact resistance at the faying surface. This, in turn, resulted in a larger nugget size and a higher welding strength. This statement is further supported by Walther (2009) who also found that an increase in nugget diameter positively influences the tensile strength of resistance spot-welded joints. Additionally, increased immersion time resulted in a reduction in the thickness of the oxide layer. Due to the reducing properties of the immersion solution, the higher chemical activity accelerated oxide dissolution, resulting in a thinner oxide layer and lower electrical resistance, as thick oxides typically act as insulator (Nmadu et al. 2022). According to capacitance formula shown in Equation (1), the capacitance (C) is directly proportional to the thickness (d) of the oxide layer. As the oxide layer becomes thinner, the resulting decrease in capacitance leads to a reduction in electrical resistance, facilitating greater current flow and improving conductivity. Consequently, the weld nugget sizes were expanded.

$$C = \frac{\epsilon A}{d} \tag{1}$$

where:
 C = Capacitance
 ϵ = Permittivity of the material
 A = Surface area
 d = Thickness of the oxide layer

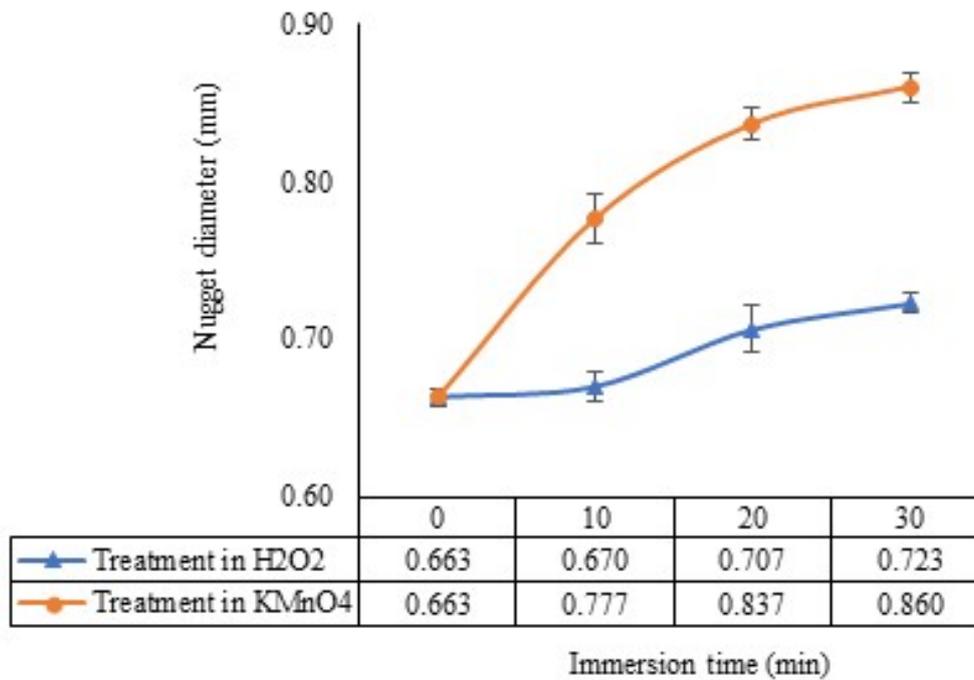


FIGURE 6. Nugget size for treated AA5052-galvanized steel weld joint

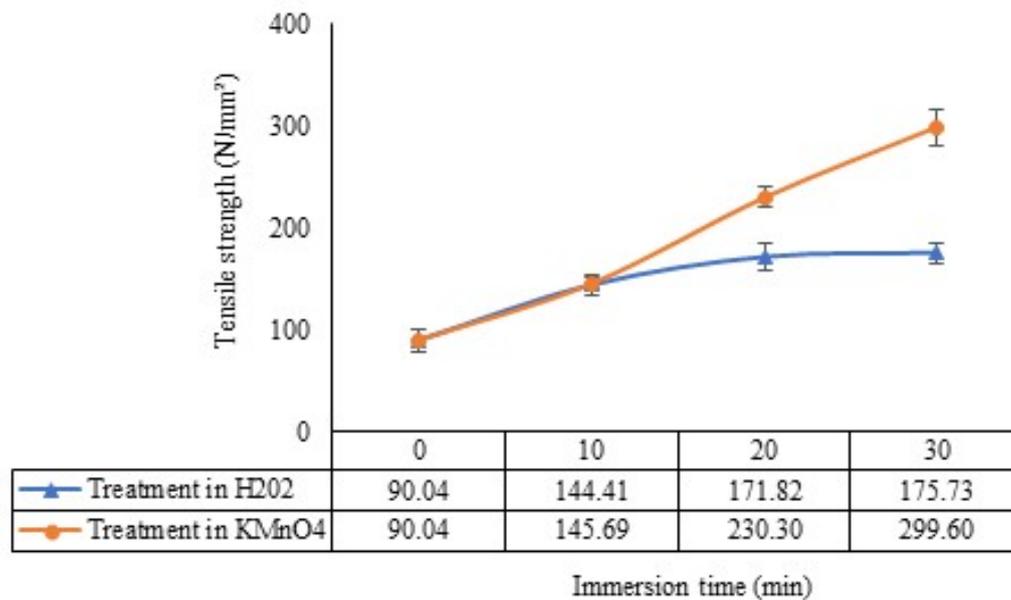
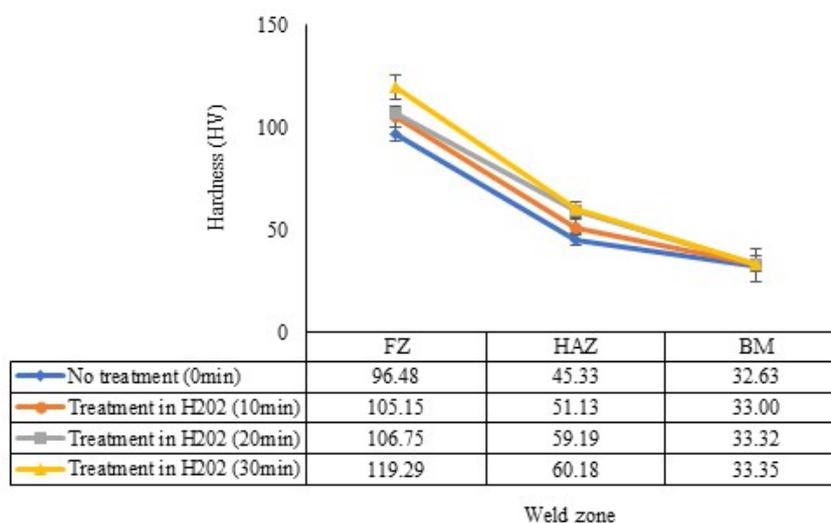


FIGURE 7. Tensile strength of treated AA5052-galvanized steel weld joint

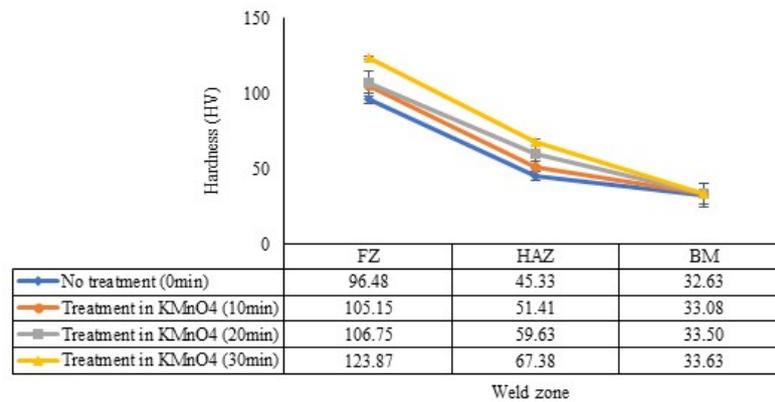
VICKERS MICROHARDNESS

Figure 8 shows the hardness of the AA5052-galvanized steel weld joint that was chemically treated by H_2O_2 and $KMnO_4$. Both H_2O_2 and $KMnO_4$ chemical treatment appear to increase the Vickers hardness of the weld joint across all weld zones. Longer durations generally leading to higher hardness. The hardness profile consisted of three zones along the interface of the sheet metal. The average hardness samples consisting of these zones corresponded to the fusion zone (FZ), heat affected zone (HAZ) and base metal (BM). Among all zones, FZ was the most important factor that crucially affected the mechanical properties of the spot weld. Comparatively, FZ offered the highest

hardness among the other welding zones of HAZ and BM. The nugget hardness in FZ was considerably high that owing to the formation of hard martensite (Tyagi et al. 2019). This finding was in agreement with Sánchez-Amaya et al. (2014) who reported that the hardness of welds is sensitive to the surface treatment and martensite was detected in FZ. The high hardness in FZ was suggested to be related to the influence of electrical contact resistance. The hardness of HAZ was higher than BM which was due to the formation of non-equilibrium phases (Pouranvari et al. 2007). The increased microhardness of the treated sample indicated less indentation than the untreated sample due to a thinner oxide layer that generated less heat.



(a)



(b)

FIGURE 8. Vickers hardness of AA5052-galvanized steel weld joint treated by (a) H_2O_2 and (b) $KMnO_4$

$KMnO_4$ treatment was more effective in enhancing hardness compared to H_2O_2 due to its stronger oxidizing capability, which facilitates the formation of crystalline manganese oxides that contribute to greater hardness. This is supported by a study conducted by Yue et al. (2024) who reported that the reaction of $KMnO_4$ with the metal surface increased Mn and O, potentially forming a harder protective layer. In contrast, H_2O_2 is mild oxidizing agent. It tends to form softer and less stable oxide layers. These oxides are usually amorphous, making them less effective in improving hardness (Kumar et al. 2022).

pH ANALYSIS

The samples immersed for 30 mins were chosen in conducting the pH analysis since sheet metals with immersion time of 30 mins displayed desired mechanical characteristics. Figure 9 shows the pH change for the AA5052 and galvanized steel immersed in H_2O_2 and $KMnO_4$ over half an hour of immersion time. H_2O_2 and $KMnO_4$ had pHs of 3.80 and 8.04 respectively before the immersion. The pH then progressively raised as the immersion time increased. Increasing the immersion time (up to 30 mins) caused the oxide layer to break down. The increase in pH value was governed by the increase in ion exchange process that dissolved the oxide layer of the sheet metals due to the continuous exposure in the chemical solution. Increasing immersion time increased ionic activity in the solution, resulting in an increase in pH.

During chemical treatment, OH^- ions originated from the oxidizing agents of H_2O_2 and $KMnO_4$ causes destabilization of the original amorphous layer of Al_2O_3 (aluminium alloy) and ZnO (galvanized steel). As a result, this dissolved the oxide layer from the substrate and leading

to a localized increase in pH (Díaz et al. 2011). At elevated pH levels relative to H_2O_2 , $KMnO_4$ from AA5052 exhibited an enhanced etching rate, resulting in greater dissolution of the oxide layer from the substrate and subsequently increased ionic activity. This finding is consistent with previous studies reported by Li & Church (2016), who studied the effect of aqueous-based cathode slurry pH and immersion time on the degradation of the oxide layer of Al. They mentioned that the oxide layer becomes attenuated when exposed to higher pH conditions and longer immersion periods. The weakening of the oxide layer at high pH levels facilitates charge transfer, promote the electrochemical reaction process, and ultimately leads to significant aluminium dissolution. Eliminating the oxide layer from the galvanised steel surface raised the susceptibility to corrosion since the surface that required protection came into direct contact with the corrosive media (Al-Saade et al. 2013). Thus, controlling the layer breakdown of galvanised steel can mostly depend on the immersion time. AA5052 had a pH better than galvanised steel. This phenomena proposed that the removal of oxide layer in AA5052 was more than in galvanised steel. The corrosion rate of aluminium was extremely low when exposed to a chemical stream with a pH between 4 and 7 (Tait et al. 2013). Nevertheless, the corrosion rate was significantly elevated when the pH was either below 4 or above 7. The addition of $KMnO_4$ to the aluminium surface produced a beneficial reaction by deteriorating the oxide film, as the aluminium was susceptible to higher pH. This situation indicated that the dissolution of the oxide layer on the aluminium surface was influenced by the pH. In addition, the higher pH of $KMnO_4$ exposed the fresh metal beneath, which accelerated the breakdown of the passive layer and caused it to collapse in comparison to H_2O_2 .

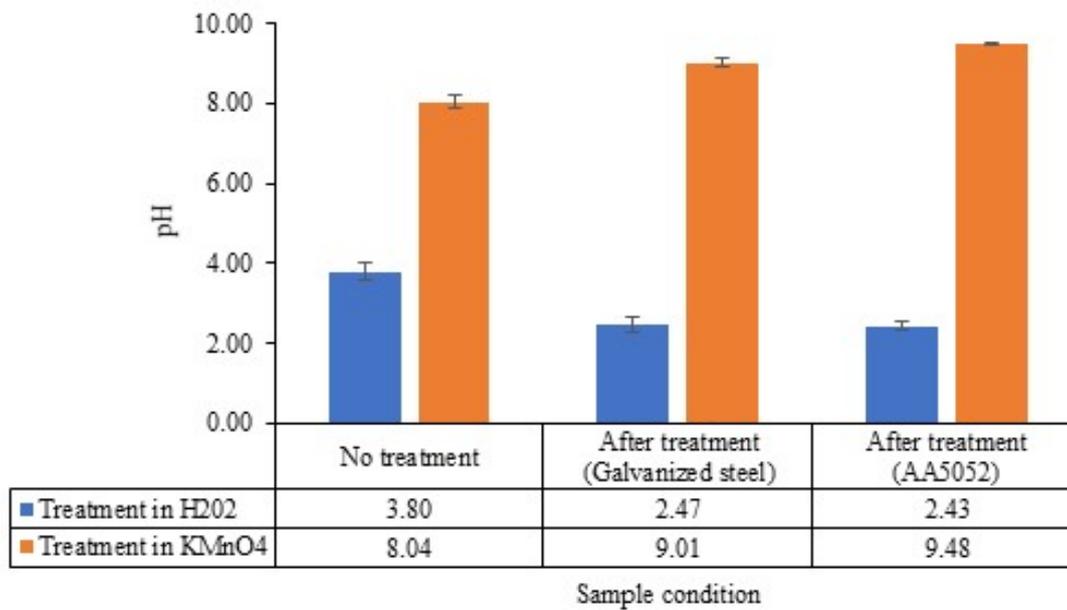


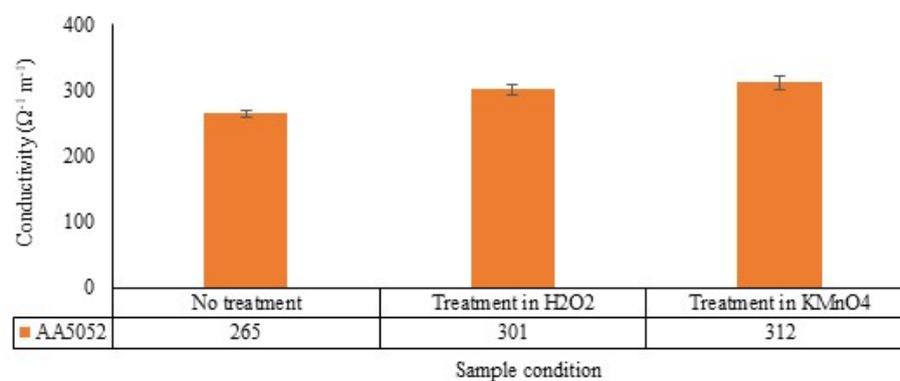
FIGURE 9. pH of galvanized steel and AA5052 before and after immersion in H₂O₂ and KMnO₄ for 30 mins

CONDUCTIVITY TEST

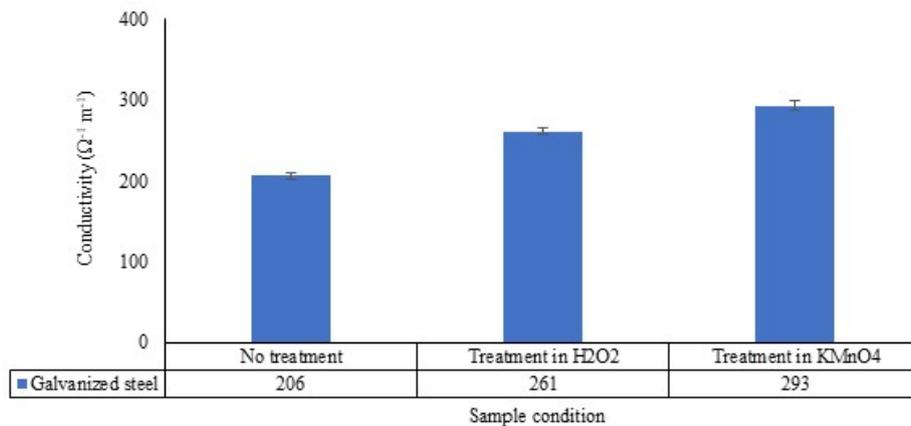
The conductive substrate was covered by an insulating oxide layer that had low heat generation and high heat conduction. Thus, high resistivity of oxide layer required higher welding current to perform the weld joint. The removal of oxide layer was necessary in providing higher thermal conductivity that could enhance the heat generation and facilitate the growth of weld nugget during welding. Therefore, additional heat input into the welding circuit from welding current could be neglected especially in the usage of small-scale spot-welding machine with low welding current setting.

Figure 10 shows the surface treatment provided a significant effect on the conductivity of AA5052 and

galvanized steel. The nugget formation was strongly dependent on the contact states at the faying surfaces (Feng et al. 2016). Hence, when the sample was treated, the conductivity of the sample started to increase due to the removal of insulating oxide layer. This condition induced the temperature of the metals to rise more quickly and generated more heat that might provide sufficient time for the weld nugget to grow up and consequently enlarged into required weld size. Furthermore, higher pH of oxidizing agent (i.e. KMnO₄) offered higher conductivity that exhibited the breakage of oxide layer on the metal surface. This situation led to a lower contact resistance at the faying surface in spot weld, hence resulted in higher heat input in this region. As a result, large size nugget was produced due to the higher current flow.



(a)



(b)

FIGURE 10. Conductivity of (a) AA5052, and (b) Galvanized steel before treated and after treated in H₂O₂ and KMnO₄

CONCLUSIONS

The mechanical characteristics of the AA5052 and galvanised steel weld joint were investigated under chemical treatment with H₂O₂ and KMnO₄. Increasing immersion time during the chemical treatment produced an increment in weld nugget diameter following welding. The ideal immersion time was 30 mins. Since the load just relied on the size of the weld nugget, the increase in diameter of the weld nugget enhanced the tensile strength even more. Nevertheless, the FZ displayed the highest hardness; HAZ and BM followed in increasing immersion time as more martensite developed from the fusion of the dissimilar materials. The oxide layer removal of the sheet metal was much influenced by the pH of chemical treatment. Because of its higher pH, KMnO₄ was able to release more OH⁻ ions, so increasing the ionic activity that resulted in greater etching rate and demonstrated the reaction in weakening the oxide layer. The removal of the oxide layer may rise as the immersion time was extended up to 30 mins. Hence, the roughness test results confirmed the validity of the higher surface roughness possessed by the KMnO₄-treated sample as compared to the H₂O₂-treated samples. The removal of the insulating oxide layer reduced the resistance while increasing the conductivity. As a result, the heat generated by the electrode could be transmitted more effectively across the metal surface, resulting in a larger weld nugget. Because the oxide layer was removed, the differences between the treated and untreated samples were clearly visible, with the treated samples having higher mechanical properties than untreated sample.

FUTURE PERSPECTIVES

Research on the effects of surface treatment on strength and hardness of aluminum alloy/galvanized steel resistant spot weld-Zn coated single lap joint marks a significant step forward in advancing the resistant spot welding of dissimilar metals. The increasing demand for lightweight yet strong materials in industries such as automotive and aerospace highlights the importance of optimising joining techniques between aluminum alloys and galvanised steels.

Innovations in welding technology such as hybrid methods that combine resistance spot welding with laser welding or ultrasonic welding could further enhance weld quality. Moreover, this approach offers more precise control over heat input which is critical when dealing with materials like aluminum and steel that have different thermal properties. In the near future, machine learning algorithms could be integrated into welding processes to predict optimal welding parameters and minimise defects. This could lead to more consistent weld quality across mass production lines, thus, reducing the need for extensive post-welding testing.

Future research should focus on long-term studies of chemically treated and welded joints, particularly under varying environmental conditions like cycling and corrosion exposure.

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DECLARATION OF COMPETING INTEREST

None.

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