Optimization on strength spot welding joint trough finite element modelling indentation approach

I N Budiarsa, I M Astika, I N G Antara and I M G Karohika
Mechanical Engineering. Dept, Faculty of Engineering, Udayana University. Kampus Bukit Jimbaran Bali 80361. Bali

Email: nyoman.budiarsa@unud.ac.id

Abstract. Failure behaviour of spot welding are important in order to design the weld strength on dissimilar spot welded joint as a significant step to reduce vehicle weight in the development of urban transportation systems. Environmental friendly. Including in this case to take positive measures to reduce CO₂ emissions and reduce fuel consumption. The material failure behaviour, properties parameter of plastics materials and fracture of materials can be easily determined when the specimen material standards (i.e parent metal) but for the results of spot welding joint testing standards are not applicable to characterize the HAZ and spot welding nugget because it is constrained by a complex structure and a small sample size. One potential approach to be developed in the behaviour of material failure, parameter plastic properties of material is to combine the numerical-experimental method. Where p-h curve indentation experimental results combined with numerical approach through Finite Element (FE) modelling. Approach was established to be used for reverse (inverse) testing of the nature of constitutive material (i.e the yield stress (σy), the coefficient of strain hardening (n)) for nugget, HAZ and the parent material (base). In this approach the Load data of material deformation used as input data for finite element model (FE) which simulates the geometry and boundary conditions of the experiment. Finite element model (FE) Model-based approaches are developed, validated then used to predict the effect of nugget size and thickness of the sheet metal on the strength of the weld joint points with different materials (dissimilar material).

1. Introduction
One effective way is the vehicle weight reduction with dissimilar metal welding solutions. The application of dissimilar metal welding is not only to reduce the weight of the car body also improves protection against corrosion and improve crashworthiness [1], [2]. Until now many dissimilar weld joint realized by mechanical assembly [3]. dissimilar welding joint is still intensively researched and developed, as interaction between the phenomenon of electrical, thermal, metallurgical and mechanical [4]. Most of the research done on the effect of the thickness and length of the welding point to the emphasis on physical and mechanical properties with the variation of the welding time. [5]. others to the problems nugget diameter size [6]. One area of research that is still active is the prediction of the dimensions and strength of the weld joint to simulate the welding process with finite element modeling [4], [7]. Another active area of research is the study of the microstructure [4]. Earlier work showed hardness value may be associated with a representative stress (σr) according to a representative strain (εr) which is the average value of the plastic strain generated in the indentation process [8], [9], [10]. The concept was developed by modeling finite element (FE) has been successfully used in analyzing the sharp indenter (vickers) where a representative strain and stress are well defined using fixed indenter angle. In this case, the resulting relationship between the material parameters and P-h curve eventually be used to estimate the hardness of the material parameters. Simulations with validated models that have been done on various material properties (σy: 100-900 MPa, and n: 0.0-0.3) the relationship between the yield stress (σy), strain hardening coefficient (n), HV and HRB have been known. This will lead to the prediction results with input hardness value, then the properties of plastics (σy and n) on a complex material such as welds, can be predicted more accurately.
2. Materials and Experimental

Two specimens with different materials and thicknesses (Stainless steel and mild steel) used in this study. As stated in Table 1.

| Table 1. Chemical composition of material spot welding test |
|-----------------|----------------|----------------|-------------|--------------|----------|---------|----------|
| Concentration   | C             | Cr             | Ni          | Mn          | Si       | P       | S        |
| Stainless Steel | G304          | <0.08%         | 17.5-20%    | <2%         | <0.045%  | <0.03%  |
| Mild steel      | 0.14%         | 0.01%          | 0.01%       | 0.32%       | 0.03%    | 0.2%    | 0.05%    |

Stainless steel used is stainless steel grade 304 with 25 mm width, 0.8 mm thickness. Other specimens are Mild steel with a width of 25 mm and a thickness of 1.44 mm. The welding on different materials combination was prepared and tested, for hardness testing samples of solid steel rod with a diameter elliptical Ø5 mm and a length of 90 mm and has a seat on the edge. Vickers hardness test is done by using Duramin-1 testing machine Struers Vickers hardness using direct loading method with a variety of loads of up 19.61 N to 490.3mN. Indenter has the right pyramidal shape with a square base and an angle of 136° to face the opposite side [11].

Welded joint on combinations of dissimilar material sheet metals are prepared and tested. Tensile shear tests performed using the Lloyd LR 30K Universal material testing machine to test tensile shear and compression. Machines with a maximum capacity of 30 kN with readings accurate to 0.5% of the force. This machine is connected to a microcomputer which allows the graphics output of the test results and test data can be obtained and stored. Tensile shear test specimens with an initial load of about 50 N, clamped with two gaskets to avoid bending during testing. Tensile test performed on loading rate of 5 mm/min based on standard ASTM E 8-04.

3. Material Models

Based on Hooke’s law and Von Mises criteria, then the true strain (ε) true stress (σ) is generally expressed as.

\[
\varepsilon = \begin{cases} 
\frac{\sigma}{E} & \text{for } \sigma \leq \sigma_y \\
\sigma_y / E \left( \frac{\sigma}{\sigma_y} \right)^{1/n} & \text{for } \sigma > \sigma_y 
\end{cases}
\]

(1)

Where E is the Young’s modulus, n is the strain hardening coefficient. In the region of the plastic, the strain could be described as the yield strain (σy) and true plastic strain. As for knowing the behavior of the failure and fracture properties of spot welded joint used Gurson Model approach. Gurson model is widely used in ductile fracture mechanics, where the fracture of materials is considered as a result of the growth of emptiness (void) in the volume of material. Gurson model most commonly used in the analysis of the failure behavior as described in the Gurson Tvergaard Needleman (GTN) model [12] assumed properties of plastics are produced from a resilient porous material, in which the yield surface is a function of the void (void) as follows

\[
\Phi = \frac{35 j k S_{jk}}{2 \sigma_y^2} + 2 q_1 f \cosh \left( \frac{3 q_1 \sigma_m}{2 \sigma_y} \right) - (1 + q_2 f^2) = 0
\]

(2)

Where σy is the yield stress of the material, σm is the mean stress, f is the volume fraction of voids. f=0 means that the material is fully dense and conditions Gurson yield reduces von Mises; f=1 means that the material is full void and has no stresses. S_{jk} is deviator components (j,k=1,2,3), is defined as S_{jk} = σ_{jk} - σ_m δ_{jk} and δ_{jk} is Kronecher delta δ_{jk} = 1 if j=k and δ_{jk} = 0 if j≠k. Some parameter values q_1,
$q_2$, $q_3$ are material constants, the values of the most encountered in most of the literature is as. $q_1 = 1.5$, $q_2 = 1$, $q_3 = 2.25$. In the power law of Elasto-plastic if representative strain ($\varepsilon_r$) is a plastic strain point of reference, the stress Representative strains ($\sigma_r$), represents the mean plastic strain defined by Tabor (1948). The techniques for estimating a point on the curve true stress-true strain is developed, in this case representative stress ($\sigma_r$) can be expressed as:

$$
\sigma_r = \sigma_y \left(1 + \frac{E}{\sigma_y} \varepsilon_r\right)^n
$$  \hspace{1cm} (3)

In indenting occurred on Elasto plastic generally follows the Power law where the load $P$ can be written as: \cite{13}

$$
P = P (h, E, v, Ei, vi, \sigma_y, n)
$$  \hspace{1cm} (4)

Where $E$=Young's modulus indenter, and $v$= Poisson ratio. By combining the effects of the elasticity of an elastic and elasto indenter solid plastic can be written:

$$
P = P(h, E^*, \sigma_y, n)
$$  \hspace{1cm} (5)

Where $E^*$

$$
E^* = \left[\frac{1-v^2}{E} + \frac{1-v_i^2}{E_i}\right]^{-1}
$$  \hspace{1cm} (6)

In this research material systems under investigation is steel, so that the value of $E$ remains at 200 GPa value $E^*= (-187$ GPa with E indenter $= 1220$ GPa and $E$ steel $= 200$ GPa) to avoid uncertainty in the value of $E^*$ from different sources. By applying the theorem in dimensional analysis of equation (5). So loading curvature $C$ can be written as

$$
C = \frac{P}{h^2} = \sigma_y \prod (\frac{E^*}{\sigma_y}, \sigma_r)
$$  \hspace{1cm} (7)

When the dimensionless function given in equation (5), the normalization is required in connection with approach against $\sigma_y$ or $\sigma_r$. By simulating know the relationship between $C_v$ Vs normalized relationship between the properties of materials and material properties normalization Vs $C_s$ (strain hardening exponent (n) and yield stress ($\sigma_y$)). Curve $P$-$h$ for both Vickers and Spherical indentation which has the following relationship

$$
C = \frac{P}{h^2}
$$  \hspace{1cm} (8)

Where $P$ is load and (h) indentation depth at each load curve. $C_v$ is the coefficient curvature of Vickers indenting and the ball indenter designated as $C_s$ and Curvature is a function of the relationship between the yield stress ($\sigma_y$) and work hardening coefficient (n). This will give potential relationship allows prediction of material parameters of the test continuous indentation

4. Prediction Plastic Properties Spot weld

Methods to determine the nature of the plastic material with dual indenter is developed through the conclusion inverse prediction using input hardness values of materials are known to identify the constitutive material properties ($\sigma_y$, n). In the first phase, systematically developed FE models in a simulation room includes a wide range of potential material properties. In the next stage, the $P$-$h$ curve developed are used in space limit simulation. Comparative approaches have been developed to predict
material set has actually indented curvature. Through the force data (F) vs indentation depth associated with a hardness value HV and HRB. Simulations with validated models that have been done on various material properties (σy: 100-900 MPa, dan n:0.0-0.5) the relationship between the yield stress (σy), strain hardening coefficient (n), HV and HRB can be known (Figure 1)

Figure 1. Typical Surface 3D plot as the model simulation results FE Model Indentation

Figure 2 typical intersection curve σy (n, HRB) and σy (n, HV) in the FE Modeling approach for the prediction of parameters constitutive material (σy, n) for the parent metal (base)
5. Conclusion

Methods to determine the nature of the plastic material with dual indenter is developed through the conclusion inverse prediction. Inverse method using a numerical approach to the value of the constitutive material (σy, n) based on static indentation has been developed and validated. Evaluation is based on the experimental data showed similarities accurate numerical approaches indented continuous curve. The developed approach has been successfully used to characterize the plasticity of different zones at welds spot welding. (Nuggets: σy = 780 MPa, n= 0.12, HAZ: σy = 745 MPa, n=0.15, Base: σy =700 MPa, n=0.17). This plastic material parameters used in finite element modeling for tensile shear deformation spot welding and welded joints showed good correlation with experimental results. Validated FE models are then used to predict the effect of nugget size and thickness of the sheet metal on the strength of the weld joint points with different materials (dissimilar material).

Acknowledgements

This research/article’s publication is supported by the United States Agency for International Development (USAID) through the Sustainable Higher Education Research Alliance (SHERA) Program for Universitas Indonesia’s Scientific Modeling, Application, Research and Training for City-centered Innovation and Technology (SMART CITY) Project, Grant #AID-497-A-1600004, Sub Grant #IIE-00000078-UI-1.

References

[1] Todd Litman, Comprehensive Evaluation of Energy Conservation and Emission Reduction Policies,”Transportation Research A, Vol. 47, January (2013), pp. 153-166
[2] Anaraki A.G., et al., Experimental and numerical analysis of low cycle fatigue of spot welded joints under peel-tension loading, Mechanical Computational, vol 221, (2002) pp.786-804.
[3] Irfan Dost, et all, Mechanical Evaluation of Joining Methodologies in Multi Material Car Body, International Journal of Advances in Engineering & Technology, ISSN: 2231-1963 Vol. 5, Issue 1, pp. 259-268 Nov. 2012.
[4] Rahman M.M., et al., An Investigation into the effects of spot diameter and sheets thickness on fatigue life of spot welded structure based on FEA, *Research Journal of Applied Science*, 3(1):10-15, 2008

[5] Nachimani C., An Experimental Investigation on Spot Weld Growth on Dissimilar Joints of 304L Austenitic Stainless Steel and Medium Carbon Steel (Part1), *International Journal of Advances in Applied Sciences (IJAAS)* Vol. 2, No. 1, (2013), pp. 25–32

[6] Aslanlar S., The effect of nucleus size on mechanical properties in electrical resistance spot welding of sheets used in automotive industry, *Materials and Design*, 27:125-131. 2006

[7] Hou Z., et al., Finite element analysis for the mechanical features of RSW process, *Journal of Materials and Processing Technology*, 185, 1-3, (2007)160-165

[8] I. N. Budiarsa, M. Jamal, "P-h Curves and Hardness Value Prediction for Spherical Indentation Based on the Representative Stress Approach", Applied Mechanics and Materials, Vol. 493, pp. 628-633, 2014

[9] N. Budiarsa, "Indentation Size Effect (ISE) of Vickers Hardness in Steels: Correlation with H/E", Applied Mechanics and Materials, Vol. 391, pp. 23-28, 2013

[10] N. Budiarsa, A. Norbury, X. X. Su, G. Bradley, X. J. Ren, "Analysis of Indentation Size Effect of Vickers Hardness Tests of Steels", Advanced Materials Research, Vols. 652-654, pp. 1307-1310, 2013

[11] Bucaille J.L., et al., Determination of plastic properties of metals by instrumented indentation using instrumented sharp indentation. *Acta Materialia*, Vol. 49, (2003) pp. 3899-3918

[12] G. Cricri, et al., A consistent use of the Gurson-Tvergaard-Needleman damage model for the R-curve calculation 24 (2013) 161-174; DOI: 10.3221/IGF-ESIS.24.17

[13] Dao M., Chollacoop N., Van Vliet K. J., Venkatesh T. A. and Suresh S., Computational modelling of the forward and reverse problems in instrumented sharp indentation, *Acta Materialia*, Vol. 49, 2001, pp. 3899–391