

Determination of Weld Nugget Size Using an Inverse Engineering Technique

Randy Gu and Lianxiang Yang
Oakland University

Leonid Lev
General Motors Company

George Harmon
Chrysler Group LLC

Nan Xu and Xin Xie
Oakland University

ABSTRACT

In today's light-weight vehicles, the strength of spot welds plays an important role in overall product integrity, reliability and customer satisfaction. Naturally, there is a need for a quick and reliable technique to inspect the quality of the welds. In the past, the primary quality control tests for detecting weld defects are the destructive chisel test and peel test [1]. The non-destructive evaluation (NDE) method currently used in industry is based on ultrasonic inspection [2, 3, 4]. The technique is not always successful in evaluating the nugget size, nor is it effective in detecting the so-called "cold" or "stick" welds. Therefore, it is necessary to develop a precise and reliable noncontact NDE method for spot welds.

There have been numerous studies in predicting the weld nugget size by considering the spot-weld process [5, 6]. In a forward problem, we are provided with known material model, well-defined boundary conditions, and specific loading conditions - mechanical as well as thermal. For an ill-posed problem [7, 8], some of the known settings may be absent and a set of experimental data is made available for solving the problem. The objective of this study is to investigate the feasibility of an inverse problem technique to determining the weld nugget size using a finite element scheme incorporating experimental measurements on the surface of the weld coupons. In the technique, a mathematical model is formulated to solve the ill-posed inverse problem in which the solution sought is required to satisfy both the experimental measurement and the theoretical foundation of the problem. To demonstrate the efficiency and accuracy of the numerical scheme, several two-dimensional examples are presented. Sensitivity to the solution algorithm from the experimental data is also discussed.

CITATION: Gu, R., Yang, L., Lev, L., Harmon, G. et al., "Determination of Weld Nugget Size Using an Inverse Engineering Technique," *SAE Int. J. Passeng. Cars - Mech. Syst.* 6(2):2013, doi:10.4271/2013-01-1374.

INTRODUCTION

In the experimental study [9], one of the feasible loading methods involves a cylinder capable of exerting a magnetic force to pull the small plate away from the larger one as revealed in [Figure 1](#). Due to the optical technique to be employed, one plate is loaded while the other should be free of obstruction so it is exposed to the laser light.

An FE simulation is performed to find the off-plane deflection of a weld coupon consisting of one 150 mm × 150 mm × 1.2 mm steel plate welded to a 100 mm × 100 mm × 1.2 mm steel plate with a $\phi 5$ mm nugget. A force F is applied on the edges of the smaller plate while the four edges of the larger plate are clamped. The off-plane deformation of the coupon is shown in [Figure 2](#).

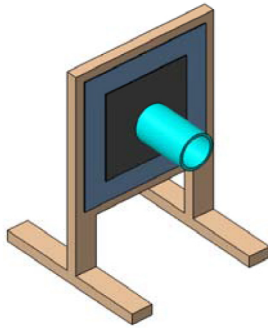


Figure 1. A magnetic force is placed in front of the smaller plate to pull it away from the larger plate. The force may be introduced using a solenoid.

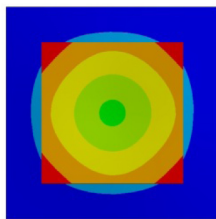


Figure 2. Deformation of coupon consisting of two rectangular plates being pulled away from each other by a force F applied at the edges of the small plate.

Clearly, the center portion closely resembles an axisymmetric problem which is adequate for developing the hybrid algorithm in the exploring phase of the project.

CONFIGURATION OF A PLANE MODEL

To explore the feasibility of the proposed hybrid approach, a two-dimensional model is employed in the development. Figure 3(a) shows the weld assembly with two concentric plates. The actual specimen used in the experimental investigation [9] is a weld assembly consisting of two square plates as shown in Figure 3 (b). The loading applied to the circular plate is assumed axisymmetric. As a result a two-dimensional axisymmetric model can be used to model the problem. If the loading applied to the square specimen is independent of the transverse angle, θ , then the stress as well as the deformation near the weld nugget would display very analogous patterns to those of the true axisymmetric model seen in Figure 3 (a).

During the investigation of the hybrid approach, the following geometric parameters for the two-dimensional axisymmetric model are used in the numerical study, Figure 4. Further, the supporting and loading conditions are:

- outer edge of the larger circular plate (bottom plate) is constrained completely,
- the smaller circular plate (top plate) is to be pulled away, and
- the total applied load is 100 N applied at the outer edge of the top plate.

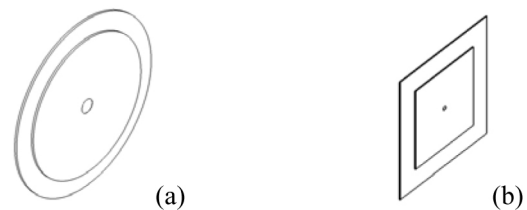


Figure 3. (a) Two concentric plates welded at the center, (b) actual specimen with two square plates used in the experimental study [9].

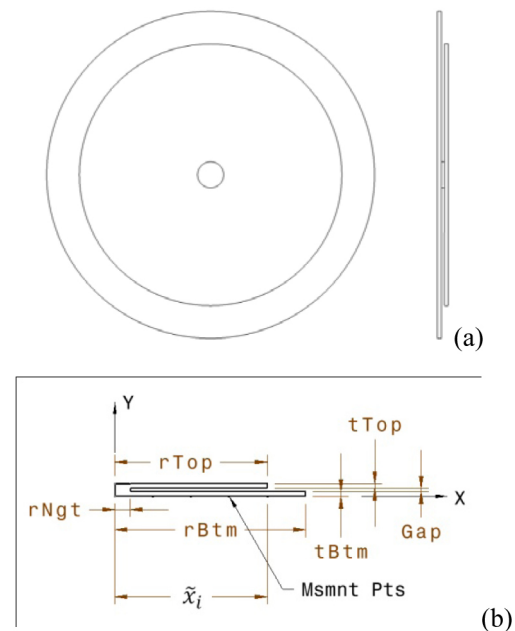


Figure 4. Projection views of the weld sample, (b) Axisymmetric model with geometric parameters and locations of measurement points $\tilde{x}_i$.

The values of the geometric parameters chosen for the numerical study are given in Table 1 below. To simulate the experimental measurements, a 2D axisymmetric finite element model is created based on the dimensions in Table 1. Note that the radius for the weld nugget may vary in different cases.

Table 1. Values of parameters used to determine the deformation of weld assembly in Figure 4.

Parms	Value, mm
rTop	50
rBtm	75
tTop	0.8
tBtm	1.2
rNgt	4
Gap	1

MATHEMATICAL FORMULATION AND NUMERICAL TEST

Let the radius of the weld nugget be r_N , the y -displacement at the measurement points with x -coordinate of $\tilde{x}_i$ be $\tilde{v}_i$, and the calculated displacement at the measurement points be v_i . The inverse problem for the hybrid approach is formulated as a minimization as given below.

$$\min_{r_N} [\text{err}] = \min_{r_N} \sum_{i=1}^n \|v_i - \tilde{v}_i\|^2 \quad (1)$$

A genetic algorithm [10, 11] is used to solve the minimization problem. The algorithm is tested using a simple example with only three measurement points equally spaced over the entire experimental measurements are given in Table 2 below.

Table 2. Simulated y -displacement of three measurement points on the bottom surface of the lower plate. The weld nugget size is $r_N = 4.0$ mm.

Point	A	B	C
$\tilde{x}_i$ Coord, mm	18.75	37.50	56.25
$\tilde{v}_i$, Y-Disp, μm	262.5	139.96	39.67

To use the hybrid approach algorithm to determine the weld nugget size, we need the following items of information:

1. Material properties;
2. Boundary conditions;
3. Applied loads;
4. Geometry of the weld assembly;
5. Surface measurements for displacement.

For a regular forward problem, it suffice with items 1 ~ 4 with a precise definition of the model geometry. In the current hybrid approach, the geometry of the model needs to incorporate an initial guess of the weld nugget size. In addition, data item 5 is supplied for calculating the real weld nugget size so that the calculated surface displacement closely matches the measured displacement.

The algorithm is tested using an initial guess for the nugget size of $r_N = 3.5$ mm. The calculated weld nugget size and the y -displacements at the measurement points are given in Table 3. It is readily seen that the algorithm performs really well.

Table 3. The calculated weld nugget size and y -displacement at the measurement points.

Variables	r_N , mm	v_1 , μm	v_2 , μm	v_3 , μm
Solution	4.00322	262	140	39.7

SENSITIVITY OF INITIAL GUESS FOR WELD NUGGET SIZE

As in many inverse problems, the role of the initial guess is critical. The sensitivity to the proposed algorithm from the initial guess for the weld nugget size is investigated in this study. First, the simulated measurements for the three equally spaced points in Table 2 are used again with various values of initial guess r_N . The calculated weld nugget size is given in Table 4.

Table 4. The calculated weld nugget size with two initial guesses from three measurement points.

No.	Nugget Size, mm		
	Guessed	Calculated	Actual
1	4.2	4.0032	4.0
2	5.0	4.0015	4.0

To further validate the algorithm, five equally spaced measurement points are used whose simulated y -displacements are given in Table 5.

Table 5. Simulated y -displacement of five measurement points on the bottom surface of the lower plate. The weld nugget size is $r_N = 4.0$ mm. Units: mm for coordinates and μm for displacements.

Point	A	B	C	D	E
$\tilde{x}_i$ Coord.	12.5	25.0	37.5	50.0	62.5
$\tilde{v}_i$, Y-Disp	297.61	222.47	139.96	67.92	18.26

Using various values of initial guess r_N , the calculated weld nugget size is given in Table 6. It is seen from these numerical tests, the initial guess of weld nugget size bears little adverse influence on the proposed algorithm.

Table 6. The calculated weld nugget size with two initial guesses from five measurement points.

No.	Nugget Size, mm		
	Guessed	Calculated	Actual
1	3.0	3.9995	4.0
2	5.0	4.0003	4.0