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Modeling of the Weld Strength in Spot Weld Using Regression Analysis of the Stress Parameters based on the Simulation Study

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Abstract

To enhance the performance of spot weld joints, various improvement methods are used to strengthen the properties of welded joints. Spot welding process is very well suited for welding of various steels grades. Regression analysis is the statistical modeling technique, and it is suitable for predicting strength of welded joints. It is valuable for quantifying the impact of various loading types upon a spot weld rupture.

In the present study quantification of impact strength of spot welded EHSS steel, Mild Steel (DC05) and AHSS (DP780) were carried out, by developing the regression models. The analysis includes Material, Thickness, Test type, Test Speed as process parameters. The complete analysis will be helpful in deciding the best combinations for desired performance characteristics. Taguchi technique revealed that the impact speed is the most significant factor in weld strength followed by thickness and material grade.

Keywords: Spot Welding, EHSS Steel, mild steel, DP780, DOE Method, Regression Analysis and ANOVA

1. Introduction

The joining method has high share of costs in product manufacture and has Impact that a link failure for the functionality of the product in various industries. The Automobile industry is a driving force in the development of existing and new joint techniques. A literature survey of the behavior and modeling of weld connections has shown a limited number of relevant articles. Some information is available from Donders, Brughmans, Hermans, and Tzannetakis (2005) and Schweizerhof, Schmid, and Klamser (2000) gives recent modeling information on spot weld process as well as the advantages of using spot weld compared with the most common joining techniques.

Several investigations are reported with respect to the behavior and modeling of spot weld in steel. Lin et al. (1998) have studied the ultimate tensile strength of resistance spot welds in mild steel subjected to combined loading tension and shear loads. Sebastian et al. (Sebastian & Silke, 2012; Silke & Frederick, n.d.; Sommer, 2010) have presented a study of a spot weld for numerical analysis of automotive applications under crash loading conditions.

Although there is currently no universally accepted measure of weld performance, there are several metrics available that provide a single numerical characterization of weld performance. The weld efficiency, the weld failure time, weld separations are such metrics. A welded structure usually represents a weakness in various strength and surface hardness at weld. These low properties are limiting the use welded joints in the design of structural components. Hence to upgrade the performance of welded joints the best combination of parameters need to be used to enhance mechanical properties. Generally, the most important characteristic of quality at the welds is their strength. In its own the experiment was taken into account the strength of welds in normal, bending and shear.

2. Objective

In the present study the mathematical models are developed for impact strength in terms of weld parameters. The investigation is helpful to the safety evaluation of structure, performance. In this investigation, parameters on spot weld strength were performed by means of Taguchi method (Montgomery, 1984). Four factors, each at three levels, were selected and the experiment was designed using L_{27} orthogonal array (Chen et al., 1996). Taguchi methodology was also successfully applied for parameter optimization.

3. Method

The general approach for this study was to select weld coupon tests, compute the weld strength metrics, estimate the weld failure based on the response of the weld internal forces, and then compare the ability of the metrics to predict failure risk. Experimental validation is the important step in the modelling process to investigate the accuracy and robustness of the established model. Coupon tests were selected from a database maintained by the NAIR WSU based on the previous studies for Mild Steel (DC05), and EHSS steel (ASTM international, 2003). Each material has 3 deformation modes. A total of 6 tests were randomly selected after applying the above constraints. An effort was made to choose tests with varied weld loading types. AHSS (DP780) spot weld evaluated using simulation study only. For each test, the weld performance metrics were computed using forces measured in the test. All data traces used were checked against redundant sensor traces to ensure data accuracy; corrections for sensor bias were made as necessary. The failure was computed using the following relations (Hallquist & Manual, 1998):

$$\left(\frac{\sigma_n}{S_N}\right)^2 + \left(\frac{\sigma_s}{S_S}\right)^2 + \left(\frac{\sigma_b}{S_B}\right)^2 \leq 1 \qquad (1)$$

This failure function used to define weld behavior in Ls-Dyna as a power law combination of three stress components.

S_N , S_S and S_B = Denominator, namely law parameters, is fed into the card material in the input file to LS -DYNA (usually taken from test)

σ_n , σ_s and σ_b = Numerators in the equation are resultants as calculated in the local coordinate system in cross section planes during simulation time. Denominator shows again three stress components which are critical to rupture or failure welds. σ_n , σ_s and σ_b are the axial load and the shear load acting on the spot weld, respectively. This failure model has become widely adopted in commercial software such as ABAQUS/Explicit and LS-DYNA3D (Hallquist & Manual, 1998; SIMULIA, 2011). Usually Failure exponents of 2 give results reasonable accuracy. Failure exponents of 3 used for shear dominant cases.

In Ls-dyna, opt=8 select failure model based on stress. Resultant of stress considered are bending torsion , shear default values are denominator are 1e+20 with exponent 2.As numerator value are stress created in weld due to loading are lower than denominator. This maintain overall value less than 1 to ensure good weld conditions. However, weld failure should include the effects of weld preload which is currently not included in the analysis.Yield criteria and failure surface are treated as an elliptical boundary contour. This form elliptical shape for weld yield surface in the system of fs, fn and fb. Numerator in this equation are bounded by an elliptical boundary contour depending on the exponent

MAT_100_DA define effective plastic strain or criteria incorporating a combination axial, shear, bending stresses (Hallquist & Manual, 1998). With option OPT=8 it shows bilinear elasto-plastic behavior enhanced by state of art failure concept. Damage type=4 consider fading energy based damage. Damage will be initiated once f > 0 will occur when damage growth w which is function of plastic strain is greater than 1. Damage type 4 considers internal work done by spot weld after its failure and is supposed to be more realistic than other damage type. An inverse parameter identification used to plot failure curve. Its mathematically formulated Procedure for determining the appropriate values for the failure model (Sachin, 2014). The failure model is based on equation of an ellipse whose exponents a and b are the intersection of failure and failure by not setting a trend. As the spot weld strength limit is exceeded, numerator this equation becomes higher than denominator critical values parameter for stresses. Hence left side of equation is larger than unity and the joint is damaged and after certain time spot weld ruptured.

4. Simulation Set up and Analysis

4.1 Materials of Interest in this Study

In this paper, the mechanical properties and spot weld-ability of newly developed steels are discussed. High-strength steels have been developed for the improvement of weight reduction, crash-worthiness, and anti-corrosion properties of an auto body. All of the specimens are made of high-strength steel viz, *EHSS steel, Mild Steel (DC05) and AHSS (DP780)* of the varying thickness.The quasi-static material properties of three steel , including yield strength, ultimate tensile strength, total elongation (TE), and strain hardening exponent/index (n) are indicated in Table 1. Table 1 is a list of the steel grades that were evaluated

Table 1. Base Material properties of steel Investigated

Grade	YS (MPa)	UTS MPa)	TE (%)	n Strain hardening coefficient
EHSS steel	368	445	34	0.19
DC05 Cold rolled steel	180	350	38	0.21
DP780	430	810	22	0.16

Yield stress is undefined as 0.2 % proof stress and n value calculated as a point of 2% and 5 % total strain. The base metal used in this study is a EHSS steel initially due to its economical aspect when compared to high grade steel such as AHSS OR UHSS.. The microstructural feature of the base exhibits a yield strength of 368 Mpa. Later this steel compare with AHSS steel DP 780 and lower grade steel DC05. DP-780 has 430 MPa yield Strength whereas for grades DC05 assumed to be 180 MPa .Applications of all three steel finds in difficult interior and exterior automotive parts. A high level of consistency in the mechanical properties of this steel grade guarantees by database maintained by the NAIR WSU.The validity of the test results is discussed in detail (Sachin, 2014), here we mentioned in brief on the basis of comparison with the standard specimens, the finite element analysis and regression analysis.

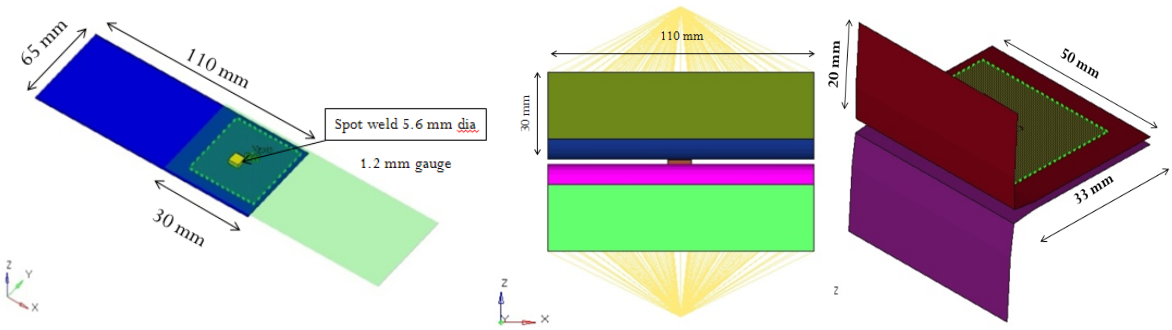
The LS-DYNA material model MAT_PIECEWISE_LINEAR_PLASTICITY model (Type 24), which utilizes the VP=0.Rate effects are accounted for with the use of scaling by the Cowper and Symonds model which scales the yield stress with a strain rate dependent factor. The accurate prediction of failure under different loading conditions is desirable. This corresponds to a plasticity with rate dependency. Inclusion of strain rate in crash analysis reduces the dynamic crush. For dynamic loadings typical of an impact, strain rate effects tend to increase the loading capacity of the material and decrease the elongation. The Cowper-Symonds formula is the standard method in LS-DYNA for taking account of this strain rate effect. It scales yield stress by the factor:

$$\frac{\sigma_d}{\sigma_s} = 1 + \left(\frac{\dot{\varepsilon}}{C}\right)^{\frac{1}{P}} \tag{2}$$

here: σ d – dynamic yield stress, σ s – static yield stress, . ε – strain rate, C,P – constants of Cowper-Symonds relation

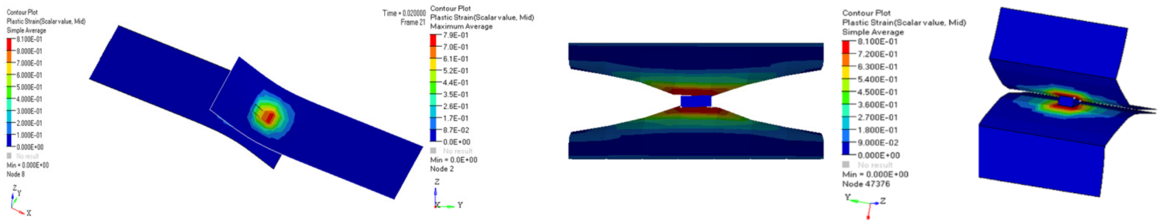
C and P are material factors determined empirically, and off-set the post-0.2% proof stress strain curve in the stress axis by the same amount.

To reproduce the spot weld behavior, a 2-D spot weld simulation is carried out. A solid element spot weld is used with shell elements for the sheet metal part, as illustrated in Figure 1. Mesh elements are selected as an optimal size for accurate results and a reduction in computational cost. The numerical analysis of this shell component with new spot weld provides a direct check of accuracy of model. Failure was defined for shell elements using the MAT 24 material model, which is equivalent to MAT 105 (PAMCRASH) (ESI Group, 2014). This will allow the material around the weld nugget to fail according to the strain and strain rate that it experienced.



(a) Shear (b) Normal (c) Peeling

Figure 1. Geometry of model specimen for 2-D weld simulation (sheet thickness 1.2 mm)



(c)

Figure 2. D3plot results of LS-DYNA analyses, and comparison of equivalent plastic strain [ε]

The stress components for normal, bending and shear loading were then collected at the observed peak loads. In substance for one point there is a plane where the shear stress is zero. The 3 principal stresses define the stress in this point respect the plane and his 3 direction. All tests on the single spot-weld specimens have indicated that failure occurs in the plate around the weld and the behavior of the weld was apparent elastic (ESI Group, 2014). Failure strain option in material card can be used to model fracture of the material. The behavior of the connection changed as a function of the loading angle. As the load angle increases, from pure shear to pure pull-out loads, the ductility of the connection increases and load carrying capacity is reduced. An interaction curve was found to adequately represent the behavior of specimens under combined pull-out and shear loading. The weld model includes failure criteria based on a critical plastic-failure strain, as well as on a force envelope. The weld model calibrated from the tests results for better correlation. Figures 3 report the fracture initiation force for each weld region which experienced failure prior to the achievement of the first peak force.

5. Quantification of various Strength using Regression Analysis

The Taguchi method is a unique statistical experimental design approach that greatly improves the engineering productivity. Taguchi suggests the production process to be applied at optimum levels with minimum variation in its functional characteristics. In general, the signal-to-noise (S/N) ratio (η, dB) represents quality characteristics for the observed data in the Taguchi method (He, Li, & Chen, 2012). S/N ratio is an index to evaluate the quality of manufacturing process. Here, the 'signal' represents the desirable value and the 'noise' represents the undesirable value, where signal to noise ratio expresses the scatter around the desired value.

5.1 Design of Experiments (DoE) by Taguchi

Number of possible attempts of full factorial experiment (what a try a unique combination of factors in setting certain levels) can be calculated by the formula. Regression analysis is well established approach to develop complex non-linear model to predict the performance characteristics. The researchers (Tang et al., 2001; He, Li, & Chen, 2012) developed a mathematical model and the adequacy of the model was verified using ANOVA. To establish the prediction model, a software package MiniTab has used to determine the regression coefficients (Minitab software, n.d.). The present work is a three factor three level problem, the available Taguchi orthogonal array is L9 & L27.In order to determine which one is suitable, and degrees of freedom (D.O.F) in both cases have to be determined. D.O.F tells about the minimum number of test runs required for a particular problem. The following formula is used to determined D.O.F

$$\text{D.O.F} = m\,(L-1) + n\,(L-1)\,(L-1) + 1 \tag{3}$$

Where m= number of variables, L= number of levels, n=number of interaction terms. From equation (3) it can be seen that number of interaction terms n = 6 (MT, MC, MV, TC, TV, CV). So m=4, L=3, n=6. After putting these values in equation (3) D.O.F becomes=2. So the number of test runs required for this problem is 33. The DoE was based on full factorial design considering five factors each at three levels. While full factorial evaluates all combinations of factors at all specified levels, it requires many runs. Therefore orthogonal array used partial full factorials set to reduce number of experiments required while still providing effective information. The appropriate orthogonal array is L27 which provides 27 test runs. Standard L 27 table selected from taguchi set of orthogonal array for DOE. The selection of process parameters is most important step in Design of Experiments (DoE). These spot welding parameters along with their levels are shown in Table 2.

Table 2. Process Parameter and their Levels

Process Parameter	Parameter Designation	Levels		
		L1	L2	L3
Material	M	Mild Steel DC05	EHSS 340	DP780
Thickness	T	0.8	1	2
Test type	C	normal (pull test)	shear (lap test)	bending (peel test)
Test Speed	V	0.001	0.1	100

The DOE variables and the values (sheet gage, test type, weld material, and strain rate) for statistical analysis are listed in Tables 2. A summary of all types of stress for the weld is also reported in DOE Table 3.The DOE statistical study was done using MINITAB statistical analysis software and major effects formulations have been developed and will be discussed further.

The purpose of the investigations described in this paper is a simulation approach for weld stresses generated in different types of coupon test. The simulation results show a weld deformation that is quite similar to the coupon test. Also the calculation of the dynamic strains correlates well with the coupon test. Therefore simulation weld model proves to be test specific robust and can be used for future analyses.

Table 3. Simulated stress output Results for Different spot weld Parameters/ DOE table and Simulated Results for Different Shot welding Parameters

Exp. No.	M	T	C	V	Normal (pull test)	Shear (lap test)	Bending (peel)
1	1	1	1	1	0.295	0.022	0.597
2	1	1	1	1	0.110	0.874	0.002
3	1	1	1	1	0.194	0.685	0.132
4	1	2	2	2	0.454	0.224	0.028
5	1	2	2	2	0.570	0.012	0.000
6	1	2	2	2	0.152	0.841	0.064
7	1	3	3	3	0.295	0.345	0.437
8	1	3	3	3	0.105	1.048	0.000
9	1	3	3	3	0.194	0.898	0.053
10	2	1	2	3	0.454	0.578	0.009
11	2	1	2	3	0.570	0.278	0.000
12	2	1	2	3	0.152	1.022	0.024
13	2	2	3	1	0.295	0.043	0.887
14	2	2	3	1	0.070	0.909	0.005
15	2	2	3	1	0.155	0.729	0.272
16	2	3	1	2	0.409	0.303	0.106
17	2	3	1	2	0.539	0.023	0.001
18	2	3	1	2	0.096	0.878	0.105
19	3	1	3	2	0.571	0.880	0.656
20	3	1	3	2	0.697	1.061	0.570
21	3	1	3	2	0.545	0.876	0.976
22	3	2	1	3	0.669	1.049	1.133
23	3	2	1	3	0.516	0.855	1.092
24	3	2	1	3	0.633	1.035	1.457
25	3	3	2	1	0.483	0.839	1.014
26	3	3	2	1	0.562	1.083	1.609
27	3	3	2	1	0.562	1.083	1.609

5.2 Regression Analysis for Quantification of Impact Strength

The ANOVA is a common statistical technique to determine the percent contribution of each factor for the experimental results (Montgomery, 1984). It is used to calculate the parameters known as sum of squares (SS), corrected sum of squares (SS'), degree of freedom (D), variance (V), and percentage of the contribution of each factor (P).The less-significant coefficients were determined from further analysis using the t-test. Also, to check the adequacy of each model, the analyses of variance were carried out by using the F-ratio test.

The ANOVA results are presented in Table 4 to 6.The Table 4 shows the following correlation between the impact strength and the process parameters as:

$$\sigma NS = 0.85 + 0.00958M + 0.00199T + 0.00133C + 0.000972V - 0.895M^2 - 0.482T^2 - 0.395C^2 - 0.293V^2 + 0.188MT + 0.022MC + 0.032MV - 0.065TC - 0.087TV - 0.085CV \quad (4)$$

Similarly, the regression analysis results for other strength component are tabulated in Table 5. It shows the following correlation between the bending strength and the process parameters as:

$$\sigma BB = 0.42 + 0.00006(M) + 0.0007(T) + 0.358(C) + 0.0004(V) - 0.507M^2 - 0.582T^2 - 0.288C^2 - 0.593V^2 + 0.688MT + 0.011MC + 0.016MV - 0.027TC - 0.08TV - 0.04CV \quad (5)$$

The shear strength component of spot weld is as follows:

$$\sigma SS = 2.15 + 0.00286(M) + 0.0369(T) + 0.358(C) + 0.0781(V) - 0.321M^2 - 0.342T^2 - 0.698C^2 - 0.223V^2 + 0.212MT + 0.015MC + 0.01MV - 0.023TC - 0.03TV - 0.035CV \quad (6)$$

The resulting regression analysis equations (4), (5) and (6) determine the approximate values of impact strength of welded steel before failure.

These all equations provide a useful guideline for setting proper values of process parameters so as to obtain desired performance characteristics of three material components viz, Mild Steel (DC05), EHSS steel, and AHSS (DP780). ANOVA, R-sq value and Adjusted R Square value are used for the validation of the models obtained by regression analysis. The ANOVA is the statistical treatment applied to determine the significance of the regression model. The R-sq is used in the context of statistical models whose main purpose is the prediction of future outcomes on the basis of other related information. It gives the information about goodness of fit for a model. In regression, the R-sq is a statistical measure of how well the regression line approximates the real data points. An R-sq of 1.0 indicates that the regression line perfectly fits in the data. Unlike R-sq, an Adjusted R Square allows for the degrees of freedom associated with the sums of the squares. Therefore, even though the residual sum of squares decreases or remains the same as new independent variables are added, the residual variance does not. For this reason, Adjusted R Square is generally considered to be a more accurate goodness-of-fit measure than R-sq. Adjusted R Square ,is a modification of R-sq that adjusts for the number of explanatory terms in the model.

Table 4. ANOVA for Normal Strength of spot weld

Coefficients and Intercepts for Tensile Normal Strength					
Predictor	**Coef**	**SE Coef**	**T**	**P**	
Constant	0.79	0.003879	256.89	0	
Material	0.00858	0.0008801	10.78	0	
Thickness	0.00199	0.000304	9.38	0	
Test	0.00133	0.0001598	9.47	0.006	
Test Speed	0.000972	0.000114	3.88	0	
S = 0.016 R-Sq = 91.0% R-Sq(adj) = 90.0%					
SUMMARY OUTPUT					
Regression Statistics					
Multiple R	0.86				
R Square	0.91				
Adjusted R Square	0.90				
Standard Error	0.016				
ANOVA for Normal Strength					
Source	**DF**	**SS**	**MS**	**F**	**P**
Regression	4	0.15291	0.03421	83.69	0
Residual Error	39	0.0149	0.00029		
Total	43	0.1812			

Table 5. ANOVA for Shear Strength of spot weld

Coefficients and Intercepts for Lap shear Strength					
Predictor	**Coef**	**SE Coef**	**T**	**P**	
Constant	2.15	0.08291	0.12	0.909	
Material	0.00286	0.01094	9.28	0	
Thickness	-0.0369	0.02263	-3.82	0.001	
Test	0.3238	0.05069	10.73	0	
Test Speed	0.0781	0.01802	4.06	0	
S = 0.0182 R-Sq = 94.0% R-Sq(adj) = 91.0%					
SUMMARY OUTPUT					
Regression Statistics					
Multiple R	0.88				
R Square	0.94				
Adjusted R Square	0.91				
Standard Error	0.018				
ANOVA for Shear Strength					
Source	**DF**	**SS**	**MS**	**F**	**P**
Regression	4	65.34	3.95	51.17	0
Residual	42	4.123	0.0032		
Total	46	66.11			

Table 6. ANOVA for Bending Strength of spot weld

Coefficients and Intercepts for Bending Strength					
Predictor	**Coef**	**SE Coef**	**T**	**P**	
Constant	0.51	0.003879	256.89	0	
Material	0.00049	0.0008801	10.78	0	
Thickness	0.0042	0.000304	9.38	0	
Test	0.0031	0.0001598	9.47	0.006	
Test Speed	0.000013	0.000114	3.88	0	
S = 0.0216 R-Sq = 93.0% R-Sq(adj) = 91.3%					
SUMMARY OUTPUT					
Regression Statistics					
Multiple R	0.82				
R Square	0.93				
Adjusted R Square	0.91				
Standard Error	0.021				
ANOVA for Bending Strength					
Source	**DF**	**SS**	**MS**	**F**	**P**
Regression	4	0.072	0.0121	56.64	0
Residual	57	0.0043	0.00026		
Total	61	0.087			

5.3 Analyzing the adequacy of the developed model

The results of ANOVA, R-square and Adjusted R Square are obtained by regression analysis using MINITAB 14 and are shown in the previous sections (Minitab software, n.d.). The results show the significance of the analysis. It is observed from Tables 4 that p-values for the response impact strength is less than 0.05, which shows that it is at 95% confidence level. R-square is the statistical measure of the exactness at which the total variation of dependent variables is explained by regression analysis. The obtained values of R-sq and R-sq (adj) are more than 0.90 and quite near to 1.0 for the performance characteristics, it indicate a good fit. This confirms that the model adequately describes the observed data.Statistical parameters for each of the models are summarized in Table 4 to 6. As another measure of model fit, the adjusted R^2 value is reported in the rightmost column of Table 4.The p-value for each term tests the null hypothesis that the coefficient is equal to zero (no effect). A low p-value (< 0.05)

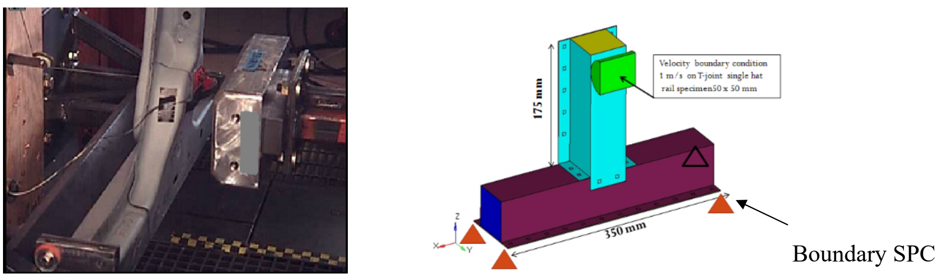
indicates that you can reject the null hypothesis. In other words, a predictor that has a low p-value is likely to be a meaningful addition to your model because changes in the predictor's value are related to changes in the response variable. Conversely, a larger (insignificant) p-value suggests that changes in the predictor are not associated with changes in the response. As per the technique, if the calculated F-ratio values of the model exceeds the standard tabulated value of the F-ratio for a desired level of confidence (say 95%), then the model may be considered adequate within the confidence limit (Stat-Ease Inc, 2000).

6. Confirmation study

A simplified model of the weld joint that enables the user to describe the global response for a component-level study is proposed. Component level structures verified for this regression results using Finite element studies.

6.1 Model Setup

Square beam parts are very common in automotive systems for absorbing energy during impact events like front and rear rails, cross members in the B-pillar structure, bumpers and B and C pillar reinforcements. Failure analysis of a T-joint is useful to improve vehicle safety since it mimics the B-pillar and sill cross-member welding region. The T-joint specimens are used for the stress in the transverse direction and also under load speeds simulating 1 m/s corresponds to strain rate 100 m/s to match with real accident scenario. For this purpose, a slide mass is identified in the amount of 192 kg to realize the failure of spot welds (Oeter, Kenan Özdem, & Hahn, n.d.). To examine spot weld failure, six side spot welds are connected, as shown in Figure 3. Validation of the simulation model is done as described in the following section. The simulations are carried out only with spot weld parameters. Furthermore, contact problems are carried out by scaling the contact thickness, as in simulations of the lap shear coupon test.



(a) Experiment loading for B-pillar weld test (b) Transverse loading of joint

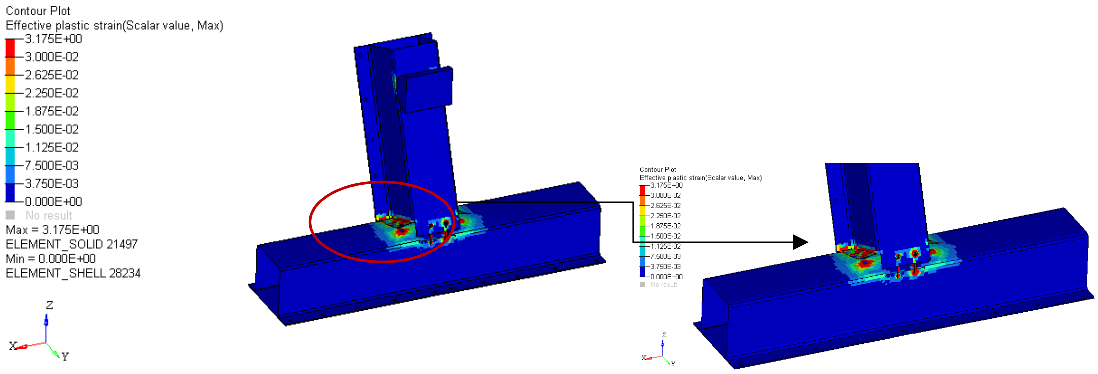
Figure 3. Simulation setup illustration of T-joint

Instead of selection of the spot weld tests data, regression model output was chosen for calibrating the material input for the spot weld model. Failure strains were obtained by benchmarking directly against the regression model.

FEA models in Ls-Dyna format were generated to simulate the crash responses of the straight rail tests. The shell elements were used to model the STEEL sheet metal. The SPOT weld was modeled by the hex type according the developed regression method. The results obtained for optimum process parameters by earlier three regression equations are used to define spot weld failure parameters on the card Define_Connections_Properties. Force resultants for Mat_Spotweld_Da are written to the spot weld force file, SWFORC, and the ELOUT file for element stresses and resultants for designated elements. In this database the resultant moments are not available, but they are in the binary time history database.

MAT_100_DA define effective plastic strain or criteria incorporating a combination axial, shear, bending stresses. With option OPT=8 it shows bilinear elasto-plastic behavior enhanced by state of art failure concept. Damage type=4 consider fading energy based damage. Damage will be initiated once $f > 0$ (equation (1)) will occur when damage growth w which is function of plastic strain is greater than 1. Damage type 4 considers internal work done by spot weld after its failure and is supposed to be more realistic than other damage type. Also structural integrity of hat-type welded structures are generally controlled by the strength of the spot welds which commonly fail under combined loading. This universal formulation applies for all of the deformation modes, i.e. U-tension, lap shear and coach peel. For each deformation mode, there is a unique set of formulation for the coefficient factors as seen in equations 5, 6,7 specific conditions of the joint design (materials, gages, loading and strain rate).

6.2 T-Shock Simulation Results



***fracture happened after the peak force has reached.**

Figure 4. Deformation contour of referenced model

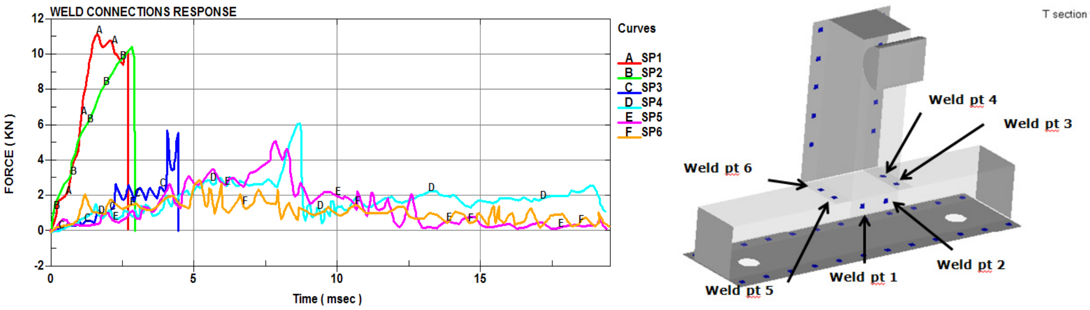


Figure 5. (a) Local spot weld forces from the simulation, (b) location of spot weld on specimen

From Figure 5, it is clear that the behavior of the force-time curves from the simulation approaches smaller peaks after the first force peaks. The SP1 and SP2 specimens fail on the same high level of shear force and significantly low in normal force. This is due to the type of loading, because the shear component influences results of the welding spots. The force levels vary little from one another. This suggests a good set of close failure criteria as per references (AVIF, 2005).

6.3 Extraction of weld strength Characteristics in This Study

Dimensionless Number was used to see failure of spot weld (Refer Table 7).This number is nothing but ratio of applied load to spot weld strength. Baseline model showing higher values for force component of shear, normal and peel as given below. Regression weld data shows lower value for theses dimensionless Number. To fully capture the deformation behavior, adjacent figure show Spot-weld Rupture/ failure is very important.

Finally graph of weld failure criteria vs time plotted to compare performance of weld seen in Figure 6. Baseline weld model to correlate with test failed at 88 ms while regression weld model failed at 81 ms. Test specimen failed at 86 ms (Sachin, P.,2014).Hence all three weld fails at approximately same time which confirm that this force based criteria can be used with accuracy for automotive steel spot weld analysis. New regression spot weld Model shows weld deformation close to test.

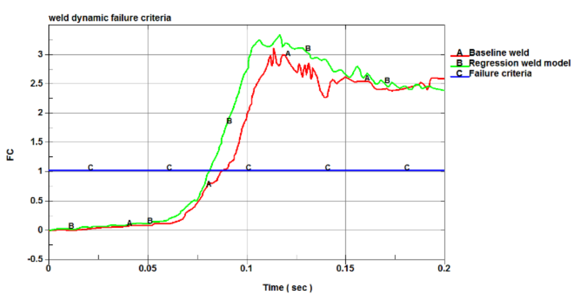


Figure 6. Comparison of weld failure time in Baseline model and Regressed weld model

Table 7. Force component history for T-joint specimen

Normalized components of failed spot weld (baseline test spec)			
sw element id	shear	normal	peel
1	0.466	1.66	0.477
2	0.477	1.044	0.530
3	0.862	0.669	0.862
4	0.466	-1.72	0.542
5	0.342	0.378	0.319
6	0.387	0.322	0.309

Normalized components of failed spot weld (Improved Design)			
sw element id	shear	normal	peel
1	0.242	0.205	0.265
2	0.419	0.046	0.500
3	0.544	0.212	0.546
4	0.455	-0.94	0.511
5	0.286	0.296	0.211
6	0.267	0.254	0.206

7. Conclusion

In the present work, a methodology of arriving at suitable combination of spot weld parameters to achieve better weld response in impact cases study is highlighted. Using regression analysis, the weld contact forces were found to offer an advantage of using previous test database for the prediction of weld failure. Although limited to an analysis of 9 coupon tests for 3 material Mild Steel (DC05), EHSS steel, and AHSS (DP780), we believe this analysis provides an important first look into how the weld contact forces compare in terms of ability to predict failure. This methodology can be extended to optimize the structures at system or subsystem level in different impact conditions.

Some tools of Taguchi method such as, Orthogonal array (OA), experimental design, analysis of variance (ANOVA) are implemented. These models are based on simulations carried out on shell spot welded specimen as well as previous experiment data. All analysis results, including, best parameter level combinations, 95% confidence intervals, R-sq and R-sq (adj) of the regression models are estimated using MINITAB 14.These regression models are correlating impact strength with process parameters. They have obtained their R-sq and R-sq (adj) values more than 0.90.

The CAE analysis based on the new formulation consistently predicts accurate crush responses of T -section type rails section specimen. The weld strength results showing here is a statistical representation of these tests. The results obtained for optimum process parameters by these equations are near to the experimental values as observed in this component level simulation study. Hence regression equations provide a useful guide for setting proper values of process parameters so as to obtain desired impact strength of steel.

A sensitivity study may be conducted on the CAE model to forecast the range of predicted results and a consideration of where the tested results lie relative to this range made. In many cases this will entail the use of additional parameters in the simulation. Sensitivity of the predicted results to idealized parameters such as friction, joint models etc., should be studied.

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