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Analysis of Spot-Welded Stiffened Plates under Compression Loading for Automotive Applications

Mr. Jayesh.Tukaram Derle[1] Mechanical Engineering Department,
K K Wagh Polytechnic Nashik
Mr. Yuvraj Suresh Khadke [2] Advanced diploma in Industrial safety Department,
K K Wagh Polytechnic Nashik

Abstract

This research focuses on improving the structural performance and safety of automotive components through the optimization of spot-welded stiffened structures. Experimental investigations were conducted alongside Finite Element Analysis (FEA) to evaluate the strength and deformation behaviour of spot-welded assemblies under various loading conditions. The findings of this study offer valuable insights into enhancing the crashworthiness and reliability of automotive structures, thereby contributing to vehicular safety.

Keywords: Spot welding, stiffened plates, crashworthiness, finite element analysis, modal analysis, compression loading, LS-DYNA, Hyper Mesh.

1. Introduction

Automobile crashes remain one of the leading causes of passenger injuries and fatalities worldwide. Among the various collision types, front and side impacts are the most common and critical in terms of occupant safety. Ensuring structural integrity and energy absorption in these scenarios is a primary objective of vehicle structural design. One widely adopted method to enhance crashworthiness is through the integration of spot-welded stiffeners onto structural plates.

Spot-welded stiffened plates are frequently used in automotive design to manage crash energy, reduce vibration, and improve structural rigidity. However, evaluating the behaviour of such structures through full-scale automotive models is computationally expensive due to high degrees of freedom. Therefore, the development of reduced, representative structural models becomes necessary to simulate real-world behaviour with less computational effort.

This research investigates the role of spot weld and stiffener design in the mechanical and dynamic performance of plates under compressive loading. Using simulation tools (LS-DYNA and Hyper Mesh) and experimental techniques (FFT analysis), this study identifies optimal configurations for crash resistance and dynamic response.

2. Literature Review

E. Rusinski, A. Kopczynski, J. Czmochowski [1]: Investigates briefly the effect of diameter of spot weld on structural characteristics. The strength of spot-welded structure is studied under compression considering effect of diameter and pitch of the spot weld. FEA study is also carried on the same structure taking into account physical and geometrical nonlinearities. The strength of the spot-welded structure is precisely determined under the test of compression. The information regarding structural details including all the parameters of the spot weld is referred for the study of dynamic analysis of spot-welded stiffeners. Matteo Palmonella, Machael I.Frisswell,Arthur W. Lees.[2]: It is shown in this paper that natural frequencies of benchmark structures are very sensitive. In this paper the techniques of model updating in structural dynamics are used to analyses and improve CWELD and ACM-2 model and guideline given for optimum implementation of design. M. D. White, N. Jones [3]: A number of quasi static axial crushing test were reported for top hat and double hat thin structures collapse modes were identified for the structures and their relative energy absorbing characteristics have been assesses. They compare the result of top hat and double hat and found that the top hat structures allow a more regular progressively collapse than double hat structures higher mean load is observed in the double hat structure. Portillo Oscar, Romero Luis Eduardo [4]: They studied that different geometrical profiles of stiffeners of different material for axial crushing of the column FE and experimental result were found that to be in good agreement in terms of force deformation curve, axial shortening, peak load, mean crushing force and folding deformed column shape. They also explained that the DP 600/300 material exhibits better crashworthiness efficiency than the DR 600/400 then they concluded the DP steels exhibit greater energy absorbing properties than the HSLA steel for the both hat type configuration S. M. Nacy, N. K. Alsahib, F. F. Mustafa [5]: Studied that the effect of residual stresses on the vibrational characteristics of plates with spot welded stiffeners of different boundary condition and spot weld location. They conclude on experimental FE base result that residual stresses produced in each nugget have significant effect on the natural frequency of the plate where natural frequency increase when residual stresses are included this effect varies on boundary conditions and distribution of spot welds of the plate. Amier Alali, Yehia Abdel-Nasser, A. Aliraqi, S. A. Swielm and Sulaiman Al-Shaye [6]: Studied analyze that transverse and longitudinal stiffeners of different configuration to sustain impact load this analysis is important for ship and tanks for perdition of collision damage FE modeling of stiffened plates using ABAQUS software is applied. They explained that the longitudinal stiffened of the struck ship using different stiffeners configuration shows little difference in the absorbing energy. M. P. Mali and K. H. Inamdar [7]: Studied that variation in spot weld position affects the final assembly with respect to geometrical quality variation simulation was conducted in the simulation a case study. The results showed that the variation in spot weld position actually has quite a large influence on variation of the final assembly. N.A. Hussain, H. H. Khodaparast, A. Snaylam, S.James, G Dearden, H Quyang [8]: includes the model updating procedure by two stages. One is the updating an FE model of the welded structure and another is the updating FE model of the individual components. The model is also analyzed by using FFT analyzer. In this study the development of the initial finite element model for its components are described. Modal testing by FFT analyzer and the modeling and updating works of the welded structure including CWELD element are discussed. The set of spot-welded hat plate structure is studied for model updating including information regarding parameter selection of the structure for analysis. The aim of the model updating study is to investigate the feasibility of utilizing one of the mostly used elements for spot weld modeling of the structure for behavior Matteo Palmonella, Michael I. Frisswell, Cristinel mares, John E Mottershead [9]: This paper gives overview of the finite element modeling of spot welds for the analysis of dynamic response of structures. The model updating on the basis of several parameters such as types of weld, structural dimensions and analysis are studied. The effects of patch shape, spot weld position and eccentricity between the patch and spot element have been investigated. They investigate that weld and patch properties greatly affect the dynamics of the structures and the effect is almost equivalent. The effect of the diameter of spot weld is very less. Hessamoddin Moshayedi, Iradj Sattari-Far [10]: investigate the effects of welding time and welding current on nugget size. Welding current is more effective on nugget growth; since increasing welding time causes more heat losses from the weld zone. Welding current should be taken as much as possible while no expulsion happens to reduce the production time and improve productivity besides achieving perfect nugget. Ahmet H.Ertas, FazılO.Sonmez [11]: this study finds the optimum locations of spot welds and the optimum overlapping length of the joined plates for maximum fatigue life. Minimum weld-to-weld and weld-to-edge distances recommended by the industry are considered as side constraints. The total strain life equation is used to predict the fatigue life. They suggest that number of spot welds significantly affects the fatigue strength. Increase in one spot weld increases the fatigue life about 20 times.

3.The objective of the study

1. Identifying & optimizing the critical parameters governing the performance of welded stiffened plate.
2. Assess the performance of the optimized structures against established automotive safety standards, to ensure that the designs provide adequate protection for vehicle occupants during collisions.

4. Methodology

4.1 Proposed Design Configurations

Twelve structural configurations (S1 to S4 with different weld patterns P1 to P3) were selected to evaluate the influence of Spot Weld Parameters like diameter, pitch, layout (P1, P2, P3). And Stiffener Profiles like cross-section shapes (top hat, double hat), dimensions, and materials.

4.2 Finite Element Modelling

Finite Element Models were created using **Hyper Mesh**, employing: Shell elements for the plates and stiffeners, CWELD elements for spot weld representation and Material properties defined with strain-rate dependence for accurate crash simulation. Boundary conditions included fixed edges and axial compressive loading. Nonlinearities (material and geometric) were incorporated.

4.3 Dynamic and Modal Analysis

Using **LS-DYNA**, dynamic simulations assessed for Natural frequencies and mode shapes, Internal energy absorption and Buckling patterns and progressive collapse is also carried out

4.4 Experimental Modal Analysis

FFT analyser was used to perform experimental vibration testing. Natural frequencies and damping characteristics were measured and compared with simulation outputs for validation.

5. Results and Discussion

5.1 Modal Analysis

1 **Structure S4P3** exhibited the highest natural frequency, indicating superior stiffness.

2 **S1P2** showed the lowest frequency, making it less ideal for high-excitation environments.

5.2 Weld Pattern Influence

1 **Pattern P1** delivered consistently better performance in modal and crash simulations.

2 **P2**, while structurally viable, lagged behind in energy absorption and stiffness.

5.3 Optimal Configuration

From the **Design of Experiments (DOE)** analysis:

1. **S4P3** emerged as the best combination, offering balanced performance across strength, stiffness, and energy absorption.

2. **Weld spacing** critically influenced deformation behavior and collapse modes. Greater spacing led to reduced interaction between stiffeners and base plate, altering energy pathways.

6. Conclusion

This research confirms that both the geometry of stiffeners and design of spot welds significantly influence the mechanical behaviour of plates under compressive loading. Key findings include:

1. S4P3 configuration provides optimal performance in terms of frequency response and energy absorption.
2. Weld patterns impact the natural frequency and deformation modes, with P1 being the most efficient.
3. Minor weld failures do not significantly impact global collapse behaviour when sufficient ductility exists in the base material.
4. The selection of appropriate stiffener profiles must consider system excitation frequencies to avoid resonance.

7. Future Scope

Several avenues for extending this research include:
Behaviour of spot-weld can be improved extracting detail spot-weld material properties.

1 Strain Rate dependent material properties need to be used to get accurate FE results.
2 Mesh flow, mesh size and mesh quality play's crucial role in fold patterns hence requires detail investigation.
3 Spot-welding operation induces localized stress concentrating hard spots these should be considered in FE modelling.

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