# Technical Note

# Fatigue Assessment of Spot Welds Based on Local Stress Parameters

*Critical annotations to formulas proposed by S. Zhang*

BY D. RADAJ

*Editor's Note: The presentation below is a critical assessment of the research paper "Approximate Stress Intensity Factors and Notch Stresses for Common Spot-Welded Specimens" by S. Zhang, published in the* Welding Journal, *May 1999, pp. 173-s to 179-s.*

The fatigue assessment of spot welds is based on local stress parameters: structural stress, stress intensity factor (SIF) and notch stress (Refs. 1–3). A high degree of expertise is necessary to define these stress parameters in a consistent manner and to apply them appropriately to the fatigue assessment of spot-welded specimens and structural members. The approximated SIF and notch stress formulas proposed by S. Zhang (Refs. 4, 5) have deficiencies, which are summarized below.

## Suitability of Local Stress Parameters

The structural stress in the overlapping plates at the periphery of the weld spot is the most important parameter for characterizing the (high-cycle) fatigue resistance of spot-welded joints. It is successfully used directly for this purpose, and is the basis for determining the stress intensity factor at the sharp slit tip or the notch stress concentration at the rounded slit tip. The structural stress is defined as membrane and bending stress linearly distributed over the plate thickness that is without the stress increase by the slit tip notch. It can be calculated rather accurately by the finite element method with fine meshing or approximated by the joint-face forces and self-equilibrating forces in the overlapping plates based on finite element results with coarse meshing, the weld spots being substituted by rigid bars. The procedures above apply to plate fractures of well-designed weld spots whereas joint-face fractures in weld spots of too small a diameter are described by the structural stresses in the nugget.

The SIF approach is less suited for characterizing the fatigue strength of spot welds because sharp slit tips seldom occur in reality and because the nonsingular stress components are neglected. The notch stress approach is also less suited because the real notch shape at the slit tip scatters with the production conditions (no data available) and because the support effect of sharp notches makes a special hypothesis necessary, which is not verified for spot welds.

A general theory of forces and structural stresses at weld spots was developed by the author (Ref. 6) together with an efficient method of determining the SIFs at the weld spot periphery on the basis of the structural stresses (Refs. 1, 2).

The design stresses of spot welds in the European automotive industry refer to the structural stress approach. The SIF approach has found some consideration in Japan. The notch stress approach is still a mere research option.

**KEY WORDS**

Fatigue
Notch Stress
Spot Weld
Stress Intensity Factor
Structural Stress

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## Deficiencies of Zhang's Approach

The main deficiencies of Zhang's approach (Refs. 4, 5) are summarized below without the theoretical details. Accurate data on stress parameters in spot-welded joints are given in Refs. 3, 7 and 8.

The SIF approach in Refs. 4 and 5 neglects the stress effects of the self-equilibrating forces. These are forces (and moments) acting in the overlapping plates without generating a joint-face force. The above means that the weld spot strength is considered as being independent of the support conditions of the plate (*e.g.*, one-sided against two-sided support in shear loading, Fig. 1) and as being independent of certain loading conditions (any self-equilibrating force system may be superimposed, Fig. 2). But the weld spot fatigue resistance depends on the support and loading conditions mentioned above.

The SIF formulas in Refs. 4 and 5 do not capture the plate width as an important geometrical influencing parameter. This has the consequence that the fatigue resistance of spot welds is considered as independent of the plate width, which is not really the case. Narrow flanges espe-

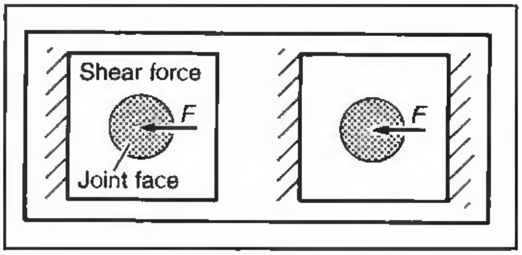


*Fig. 1 — Same joint-face shear force F, different support conditions.*

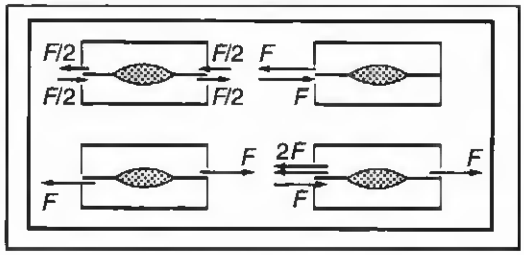


*Fig. 2 — Same joint-face shear force F, different loading conditions.*

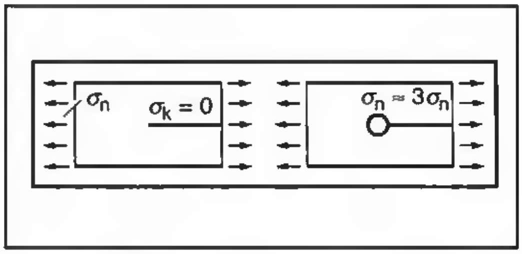


*Fig. 3 — Sharp slit tip without stress intensity (left); rounded slit tip with notch stress concentration(right).*

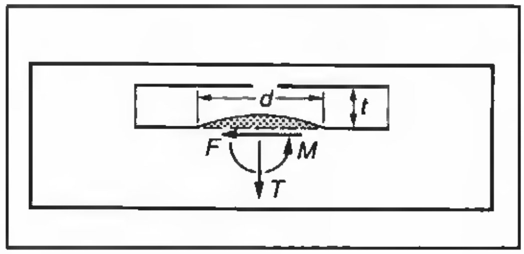


*Fig. 4 — Resultant joint-face forces.*

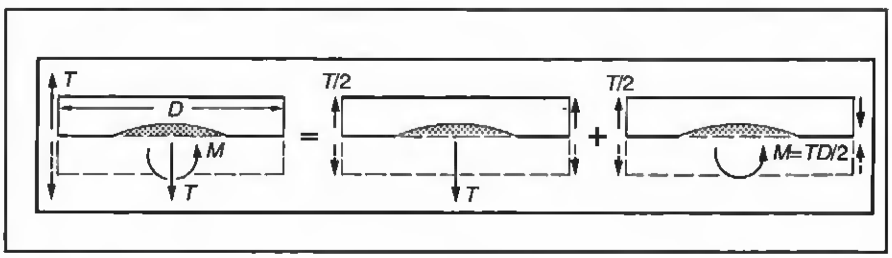


*Fig. 5 — Peel-tension loading decomposed into bending moment and cross-tension force in the joint face.*

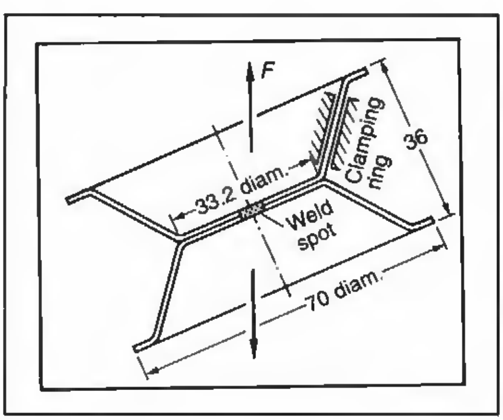


*Fig. 6 — Cross section of the double-cup specimen.*

cially need a relevant correction term in the formulas.

The notch stress approach in Refs. 4 and 5 has all the above deficiencies of the SIF approach because the stress concentration factors are derived from the SIFs based on Creager's blunt crack solution. Additionally, it is not recognized that the notch effect of the nonsingular structural stresses must be superimposed (*e.g.*, tensile stresses in slit direction generate no SIF, but a stress concentration factor of approximately 3.0 occurs with a rounded slit tip, Fig. 3). Furthermore, the large (obviously fictitious) notch radius introduced ($\rho = 1$ mm) cannot be applied to plate thicknesses in the 1-mm range without modification of the method.

The derivations in Refs. 4 and 5 mix up joint-face forces (Fig. 4) with forces in plate cross sections. The plate bending moment in the weld spot vertex point is set equal to the joint-face bending moment. Thus, the plate width is incorrectly substituted by the weld spot circumference in the relevant formulas. The correct decomposition of peel tension loading into a cross-tension force and a bending moment in the joint face is not taken into account — Fig. 5.

*Tensile-shear specimen.* The weld spot is not tensile-shear loaded from one side only, as assumed in Refs. 4 and 5, but receives about 75% of the shear force from the front side and about 25% from the rear side under the geometrical conditions considered (Ref. 7). Additionally, a finite width correction factor of 1.1 seems to be appropriate. The self-equilibrating plate bending moment $M = Ft/4$ is incorrectly introduced as a joint-face bending moment. The joint-face bending moment is really zero in the standard tensile-shear specimen.

*Cross-tension specimen.* The joint-face bending moment $M = Tc/8$ introduced in Refs. 4 and 5 does not really exist. Considered as a plate bending moment, it should be distributed over the plate width instead of the weld spot circumference. The generally accepted structural stress formula derived from plate bending theory, $\sigma_s = 0.69(T/t^2)$ ($\ln D/d$), with (equivalent) bending-rigid support spacing $D$ (Ref. 2) is not recognized.

*Coach-peel specimen.* The joint-face bending moment $M = eP$ introduced in Refs. 4 and 5 is once again a plate bending moment in reality and should be treated accordingly.

*H-shaped specimens.* A surprisingly large tensile-shear force occurs in the peel tension variant of the specimen (Ref. 8), which is incorrectly neglected in Refs. 4 and 5.

*Double-cup specimen.* The cross section of the specimen is incorrectly given in Ref. 4. The correct view is plotted in Fig. 6.

*Hat profile specimens.* It is not sufficient to evaluate the structural stress in the weld spot vertex point produced by the joint-face shear force as proposed in Ref. 4. Further joint-face forces have to be considered: a torsional moment in the weld spot and, in the case of the single-hat profile specimen, a longitudinal bending moment (Refs. 3, 6). The relevant SIF formulas should include a flange width correction.

*Structural members.* The SIF formulas for spot welds under general loading conditions in structural members proposed in Refs. 4 and 5 are certainly not generally applicable. They do not include any parameters or terms representing the support and loading conditions of the overlapping plates. They should comprise the complete set of joint-face forces and self-equilibrating forces modified by the influence of plate width and support spacing.

## Conclusions

The SIF formulas for spot welds proposed in Refs. 4 and 5 are incomplete, partially incorrect and bound to the special geometrical, loading and support conditions considered. They do not differentiate between the different variants of specimens and do not solve the problem of transferability of fatigue data in a more general form. The notch stress formulas have additional deficiencies. A better approximation of the structural stresses and the SIFs derived therefrom is possible. The notch stress approach is still a mere research option.

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