Technical Note

Approximate Stress Intensity Factor and Notch Stress for Spot Welds

Answer to the critical annotations by D. Radaj

BY S. ZHANG

The analytically approximated formulas of the stress intensity factor (SIF) and notch stress for spot welds (Refs. 1, 2) are commented in Ref. 3, inclusive of some general comments on the local approach to fatigue assessments of spot welds. The local approach was first proposed by Pook (Ref. 4). The comments mainly focus on the secondary effects that are neglected with justifications in Refs. 1, 2. The formulas intend to capture the main effects of the key design parameters for spot welds, notably nugget diameter and sheet thickness. Although the comments do not affect the correctness of the formulas under the given conditions, they are still answered for clarification.

Local Stress Parameters

The local stress parameters (structural stress, notch stress and SIF) are preferred in fatigue assessments of spot welds mainly for two reasons. First, the fatigue test data from different spot-welded specimens are better correlated by these parameters. Second, the local stress parameters capture, besides the load, the effects of the key design parameters for spot welds.

A spot-welded joint is treated as a crack or notch problem and then analyzed by fracture mechanics methods, as shown by the vast amount of investigations in the last two decades. The SIF and notch stress for spot welds are less widely applied than the structural stress because of the expenditure and uncertainty in determining these stress parameters.

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The method of determining the SIFs at spot welds (Ref. 5) is in fact far from efficient if taking the determination of the applicable structural stresses at the spot welds into account. The coordinate system was not clearly defined in Ref. 5, which may lead to an incorrect sign for the mode II SIF. This is an uncertainty of the method. It is inefficient for variations of nugget diameter and sheet thickness. This was one of the reasons that inspired Refs. 1 and 2 to develop simple formulas for spot welds.

Approach of the Author

The SIF and notch stress for general spot welds are determined analytically by structural stresses around the spot welds or estimated hy the interface (joint face) forces and moments in the spot welds (Refs. 1, 2). For common spot-welded specimens, simple formulas are obtained. The uncertainty of the method (Ref. 5) is clarified in Refs. 1 and 2.

The SIF formulas for the common spot-welded specimens are derived by two steps. First, the SIF is determined analytically by the structural stress. Second, the structural stress is analytically approximated. The self-equilibrating forces are captured as well because the complete structural stress (excluding the secondary stress neglected) is used in the derivation. It holds true for the notch stress formulas.

KEY WORDS

Fatigue
Notch Stress
Spot Weld
Stress Intensity Factor

The plate width is assumed to be significantly larger than nugget diameter, as is the case in practice for most spot-welded specimens. It is then neglected as a secondary effect. This is supported by both finite element and experimental results (Refs. 1, 2). The two cases (Fig. 1 in Ref. 3) make remarkable difference in terms of the local structural stress at the spot weld only in the case where the plate width is comparable with the nugget diameter, as shown in the figure. But this case has been ruled out by the assumption. However, the narrow flanges of the hat profile specimens have been approximately considered by the correction factor k in Ref. 1 (see Equations 14, 18, Ref. 1). Figures 2, 4 and 5 in Ref. 3 do not help understand the derivation of the formulas. The derivation is based on the analytic approximation of the structural stresses instead of the interface forces at spot welds. The stresses are related, via three-dimensional rigid inclusion solutions, to the applied load or moment of the specimens. The relations are given in detail (Refs. 1, 2).

The self-equilibrating forces are neglected in the formulas for general spot welds in structural members (Equations 36–40 in Ref. 1). They are also neglected in the structural stress approach. The interface forces, instead of self-equilibrating forces, prevail for most practical load-

ing conditions. There is still no reliable theory on the self-equilibrating forces for spot welds. This makes it difficult to consider the self-equilibrating forces.

The nominal structural stress is superimposed on the singular part of the notch stress to obtain the complete notch stress (Refs. 1, 2). The notch stress reduces to the nominal structural stress when notch root radius is infinitely large and turns into the crack stress when it approaches zero. This is reasonable. It cannot be checked numerically for the time being because of a lack of the finite element results. The only possible check now is to correlate fatigue test data gathered from different specimens by using the derived notch stress to see whether the scatterband of the data is reduced as significantly as by using the SIF. This is done in Ref. 1 (see Figs. 9 and 10, Ref. 1) and the result is positive. Figure 3 in Ref. 3 is not relevant to spot welds. The gap between spot-welded sheets can be treated as an open notch but not a hole.

The fictitious notch root radius is related to material properties and unambiguous for a given material (0.2 mm for ferritic steels). The same radius should be used for the same materials. A fictitious radius of 1.0 mm was introduced as an example to demonstrate the application of the notch stress formulae (Refs. 1, 2). The notch stress method (Ref. 5) fails with plate thickness also of 1.0 mm because the method makes real rounding. But it does make sense for the current method. A fictitious radius of 1.0 mm for a plate thickness of also 1.0 mm means the notch effect is very weak. The structural stress prevails at the spot weld. This is reflected in the formulas by introducing the large radius. This also explains why a reasonable correlation can be achieved despite a large notch root radius (Fig. 10 in Ref. 1). The reasonable correlation remains at a smaller notch root radius.

The discrepancy of the SIF data given in Ref. 6 for a tensile-shear specimen is as large as 10% (Table 8.1, Ref. 6). It is not clear what amount of discrepancy exists in the other data. The notch stress compiled in Ref. 6 (Equation 8.52, Ref. 6) is incorrect due to a superposition of stresses at different locations. The newly derived notch stress (Refs. 1, 2) is considered as a substitute for the incorrect notch stress.

For the tensile-shear specimen, there is a bending effect causing the mode I SIF. For the cross-tension specimen, the bending stress prevails at the spot weld and corresponds to a moment. It is not the joint-face bending moment as interpreted in Ref. 3. This moment should not be distributed over the plate width at the spot weld like a two-dimensional problem. It is a three-dimensional problem and should be treated accordingly by the rigid inclusion solution, as done in Ref. 2. This applies to the coach-peel specimen in a similar manner. The effects commented on the H-shaped and hat-profile specimens are secondary in comparison to the prevailing effects captured by the formulas. The "surprisingly" large tensile-shear force in the peel tension H-specimen is compensated by the large moment in terms of mode II SIF. The end effect is that the mode II SIF is nearly zero, as clearly shown by another figure in the same literature. The mode II SIF is then fully negligible. The double-cup specimen shown in Ref. 1 is used mainly to illustrate the definition of the geometric parameters, but its cross section is incorrectly shown. The correct one is given in the original literature (or Ref. 3). For structural members, the support and loading conditions are reflected by the forces and moments in the formulas. It is obvious the forces and moments in the spot weld change with the different support and loading conditions. For spot welds in complex automotive structures, plate width and support spacing are hardly definable.

Conclusions

The comments (Ref. 3) on the formulas (Refs. 1, 2) focus mainly on the secondary effects, which are neglected with justifications and do not affect the correctness of the SIF and notch stress formulas under the given conditions. All the SIF formulae for the specimens are favorably compared with the available finite element results.

The structural-stress-based formulas are complete. The formulae for specimens are complete and bound to the special conditions of the specimens. The force-based formulas for general spot welds are incomplete where the self-equilibrating forces are neglected with justifications. The different variants in nugget diameter, sheet thickness, load spacing or eccentricity, spot pitch and loading angle are covered by the formulas. The transferability of the fatigue data is demonstrated in terms of both SIF and notch stress. The data are transferred by the formulas without finite element analysis. The correlated endurable SIF (fatigue strength) agrees well with the result from the literature. The endurable notch stress is not available from the literature.

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