C. Effect of Manufacturing Variables on the Effectiveness of Spike Tempering During Spot Welding Advanced High Strength Steel

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Introduction

Fuel efficiency standards promote lightweight automotive structural designs that rely on high-strength steels to optimize weight, cost, and performance. HSS are still preferred over alternative lightweight materials due to the relative cost. Recently, a range of advanced high strength steels (AHSS) have been introduced. These include dual-phase (DP), transformation induced plasticity (TRIP), and martensitic grades. All of these grades appear to meet requirements for formability, but weld metal fracture due to resistance spot welding (RSW) has been a concern. More specifically, these grades of materials are susceptible to a phenomenon know as hold time sensitivity (HTS). HTS is usually demonstrated during peel tests, where longer hold time yield interfacial failure modes.

Recent investigations have shown reductions in HTS through in-situ tempering. These studies were conducted in order to develop acceptable welding and tempering conditions for the steel grades mentioned above. Results from these investigations have shown that short temper schedules (spike tempers) are effective for improving weld metal fracture toughness while retaining joint strength. The effects of manufacturing conditions on the usefulness of this technique, however, are unknown.

Approach

This work examined the effect of typical manufacturing variables on the effectiveness of spike tempering. The study involved two grades of 1.6-mm thick DP steel (DP600 and DP980), and one grade of 1.6-mm thick martensitic steel (M1300). Manufacturing factors included geometric concerns (sheet fit-up, sheet alignment, sheet gap, button size), electrode wear concerns (electrode face diameter), and tempering concerns (quench and temper time). To facilitate this work, experimental design (DOE) methodologies were employed. Results from the DOE were used to develop empirical models that related processing conditions to both static and dynamic mechanical properties. The models were ultimately used to graphically depict the relative effect of each factor on mechanical performance, as well as, the robustness of spike tempering.

Discussion

Factors which affected the geometry of the specimen clearly dominated the performance of welds made on all three grades of steels. These included the electrode face diameter, the weld position, the weld size, and the angular alignment. The most important of these attributes was the size of the weld itself. In these studies, the hardness profiles suggest significant toughening of the weld microstructure, and the micrographs do not infer the presence of extensive porosity. As a result, stress state appears to be the dominant cause of performance variations. For static testing, the larger weld sizes both increase the overall bond area, and promote nugget rotation, reducing tendency for shear-type failures. Both directly affect the required load to produce failure.

Conclusions

Specific conclusions from this program include:

1. Overall robustness of the spike-tempering approach: Overall process robustness for the application of spike tempering was dominated by geometric effects. There was relatively less influence of actual spike-tempering variables (temper time, quench time) on joint performance.

2. Failure modes during mechanical testing: All welds failed by either shear or button pull-out. This is a reflection of toughness improvements associated with spike tempering across the range of materials, setup conditions, and tempering conditions used in this study.

3. Significance of geometric factors: Geometric factors dominated the results seen in these experiments. In particular, large weld sizes were the single strongest factor affecting weld performance. This was related to the load bearing area of the weld, as well as the reduced stress concentration factors associated with larger weld sizes. Factors, which influenced the degree of nugget rotation during testing (e.g., edge position), also affected the results, especially impact performance.

4. Relative sensitivity of the materials tested: All materials showed the same general trends regarding variations in mechanical properties during these experiments. Minor differences in material performance were related to the relative hardness of the tempered welds, as well as HAZ softening for the higher strength variants.