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Effects of fusion zone size and failure mode on peak load and energy absorption of advanced high strength steel spot welds under lap shear loading conditions

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Abstract

This paper examines the effects of fusion zone size on failure modes, static strength and energy absorption of resistance spot welds (RSW) of advanced high strength steels (AHSS) under lap shear loading condition. DP800 and TRIP800 spot welds are considered. The main failure modes for spot welds are nugget pullout and interfacial fracture. Partial interfacial fracture is also observed. Static weld strength tests using lap shear samples were performed on the joint populations with various fusion zone sizes. The resulted peak load and energy absorption levels associated with each failure mode were studied for all the weld populations using statistical data analysis tools. The results in this study show that AHSS spot welds with conventionally required fusion zone size of $4\sqrt{t}$ cannot produce nugget pullout mode for both the DP800 and TRIP800 welds under lap shear loading. Moreover, failure mode has strong influence on weld peak load and energy absorption for all the DP800 welds and the TRIP800 small welds: welds failed in pullout mode have statistically higher strength and energy absorption than those failed in interfacial fracture mode. For TRIP800 welds above the critical fusion zone level, the influence of weld failure modes on peak load and energy absorption diminishes. Scatter plots of peak load and energy absorption versus weld fusion zone size were then constructed, and the results indicate that fusion zone size is the most critical factor in weld quality in terms of peak load and energy absorption for both DP800 and TRIP800 spot welds.

Keywords: Advanced high strength steels; Resistance spot welds; Failure mode; Failure load; Energy absorption

1. Introduction

Because of their excellent strength and formability combinations, advanced high strength steels (AHSS) offer the potential for improvement in vehicle crash performance without extra weight increase. Currently, two types of advanced high strength steels are being used in the automotive industry. One is the Dual Phase

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(DP) steel in which ferrite and martensite are the primary phases and its mechanical properties are controlled by the martensite volume fraction and the ferrite grain size [1,2]. The second is the TRansformation Induced Plasticity (TRIP) steel, in which bainite and/or martensite plus fine islands of retained austenite are embedded in a fine-grained ferrite microstructure. The presence of retained austenite in TRIP steels enhances ductility at a particular strength level by means of a phase transformation from austenite to martensite. This phenomenon involves formation of strain-induced martensite by deformation of metastable austenite and leads to an increase of strength, ductility and toughness of the steel.

Dual phase and TRIP steels are alloyed to control the amount and transformation of intercritically formed austenite. The carbon contents in these steels typically range from 0.05 to 0.2 wt% C, and the manganese content may be up to 1.5 wt%. In TRIP steels, Si or Al additions are also made to limit cementite formation, thus enhancing the amount of retained austenite present after isothermal transformation, and P may be added as a ferrite solid-solution strengthener [1]. Because of the relatively high carbon equivalents in AHSS, it should be anticipated that the steel microstructures in the heat affected zone will be significantly modified by different welding processes.

Spot welds are the primary method of joining automotive structural components. A vehicle's structural performance depends in part on the welded-joint structural integrity [3–5]. It is well known that in some vehicle safety regulated systems, such as fuel system, joint performance can dramatically alter the system performance. As a means of quality control for spot welds of mild steel, the US automotive industry has historically used destructive tests such as the peel-test, or chisel test to determine whether a satisfactory weld has been produced. The common criterion is that the average weld button diameter (D) should be equal to or larger than $4\sqrt{t}$ (t defined as material thickness in mm). Undersized welds have an average weld button diameter larger than $2\sqrt{t}$ but less than $4\sqrt{t}$. Defective welds have average weld button diameters less than or equal to $2\sqrt{t}$. Some welds that fail in the interfacial fracture mode in conventional steels would be considered unacceptable and would be rejected by the quality control inspector [6,7]. Welding engineers have also adopted $4\sqrt{t}$ as the target fusion zone size in developing the appropriate welding parameters for mild steel.

This historical criterion works well for spot welds of mild steel because the weld nugget has a significantly higher hardness (hence yield strength) than the base material, hence nugget pullout around the heat affected zone (HAZ) should be the desired failure mode based on fundamental mechanics strength estimation [11–14]. Any weld joint that separates in the interfacial fracture mode would indicate lack of fusion or small fusion zone size and therefore would not meet the necessary joint strength requirements. The effectiveness of this criterion for evaluating AHSS spot weld, however, has not been adequately addressed in the automotive welding community; it was simply adopted from the mild steel practice and applied to AHSS spot welds.

In this paper, we examine the effects of fusion zone size on failure modes, static strength and energy absorption of resistance spot welds of DP800 and TRIP800 spot welds under lap shear loading condition. The critical weld fusion zone size for nugget pullout depends on the base metal mechanical properties, the properties of the weld zone and heat affected zone, as well as the weld coupon geometry. Static strength tests using cross tension samples were performed on the joint populations with controlled fusion zone sizes in an earlier study [16]. In this study, we report the static weld strength test results under lap shear loading condition for joint populations with various fusion zone sizes. Peak load and energy absorption levels associated with each failure mode were then studied using statistical data analysis tools. The weld test results show that, under lap shear loading, the weld fusion zone size is a critical factor in its static performance in terms of failure mode, peak load and energy absorption. Moreover, AHSS spot welds with fusion zone size of $4\sqrt{t}$ cannot produce the desired nugget pullout mode for both the DP800 and TRIP800 materials examined. Similar approach has been used in studying the effects of fusion zone size and failure modes on the peak load and energy absorption levels of aluminum spot welds [6,8].

2. RSW sample preparation and micro-hardness comparison

The experimental work in this investigation consists of quasi-static tests of lap shear welded samples of DP800 and TRIP800. The DP800 sheet is 1.6 mm thick with a galvanized coating and the TRIP800 sheet is 1.5 mm thick, uncoated. Following the naming conventions for advanced high strength steels, these two steel materials should both have an ultimate tensile strength (UTS) of 800 MPa. Room temperature stress