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Failure characterization of spot welds under combined axial–shear loading conditions

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ABSTRACT

This paper proposes an accurate failure criterion of spot welds under combined axial and shear loading condition. Test fixtures and a specimen were newly designed with the aid of information from finite element analysis results in order to obtain the failure load of a spot weld under the combined load with the constant ratio of the shear load to the axial load. The testing apparatus designed involves a pin-joint between a loading frame and a testing fixture for improved constraint conditions and a cross-type specimens spot welded using guide plates in order to assure the constant ratio of the shear load to the axial load preventing a spot weld from rotating during the test. Using the designed test fixture and specimens, failure tests of spot welds were conducted with the variation of seven different loading angles in order to obtain failure loads and identify failure modes at each angle. Failure loads of spot welds were investigated with experiments for three different materials of a mild steel, a high strength steel and an advanced high strength steel (AHSS). The failure loads obtained from experiments at various loading angles are utilized to propose a failure criterion for description of failure behavior of a spot weld. The failure criterion of a spot weld as a function of the axial load and the shear load is expressed as a different function from an elliptic function, which was proposed in previous researches: the different function is called a β-norm function in this paper. It was found that the failure criterion proposed provides a fairly accurate description of the failure load obtained from experiments under combined axial and shear loading conditions.

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1. Introduction

The electric resistance spot welding process is an indispensable assembling process of steel auto-panels in the automobile industries since its introduction in 1950s. As a modern auto-body contains several thousands of spot welds, it becomes extremely important to understand the strength of spot welds under impact and fatigue loading conditions [1,2]. Failure of the spot weld is likely to occur prior to failure of the base metal when a large load is applied to the structure since extremely high stress is concentrated at the interface between the nugget and the base metal. As the load transferred from one part to a joining part is abruptly changed after the spot weld fails, behaviors of the structure usually reveal large discrepancies between the experiment and the finite element analysis after joined components are separated.

Failure of a spot weld has been a challenging issue of extensive studies both experimentally and theoretically in the past few decades. Failure tests and analyses of spot welds can be classified into two categories: the first estimates the strength of spot welds and provides related failure criteria; and the second estimates the fatigue lives of spot welds. Invaluable efforts have been devoted to estimating the fatigue life of spot welds [3–6]. In this body of research, high-cycle/low-stress fatigue tests were initially conducted using lap-shear specimens and coach-peel specimens. Researchers then calculated the parameters related to the fracture mechanics, such as the linear elastic stress intensity factor or the elasto-plastic fracture parameters of specimens in order to estimate the fatigue crack growth in the specimen using the finite element analysis [7–11]. In addition, it is necessary to estimate the strength of spot welds in order to provide a failure criterion of a spot weld in the structural analysis or crashworthiness assessment of auto-body members. For the purpose, lab-shear tests, coach-peel tests and cross-tension tests have been elaborately performed to estimate the failure loads of the spot weld [1,12–14]. Recently, several researches have been reported to consider the effect of strain rate on the strength of a spot weld [15–18]. Langrand and Markiewicz [15] have carried out extensive experiments for the failure strength of spot welds under static and dynamic combined loading. Wood et al. [16] described a strain rate dependent spot weld failure model with both

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