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车辆激光拼焊板失效模式预测及有限元验证

Prediction of failure modes and finite element verification of laser tailor welded blanks for vehicle

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作者	单位
陈水生	1. 河南理工大学机械与动力工程学院，焦作 454000
林建平	2. 同济大学机械与能源工程学院，上海 201804
王裕清	1. 河南理工大学机械与动力工程学院，焦作 454000

中文摘要:

拼焊板技术在汽车制造中得到了广泛应用，但也面临成形性下降的挑战。失效模式是拼焊板成形过程中的关键特征，要改善拼焊板成形性能，必须对失效模式进行预测。为了预测成形后拼焊板的失效模式，该文以汽车激光拼焊板为对象建立了拼焊板临界板厚比解析模型。结合理论解析法、有限元及试验法研究了拼焊板两侧母材的厚度之比（板厚比）与拼焊板母材材料参数及应变状态之间的关系，建立了拼焊板失效模式预测模型。基于等双拉应变状态，分别采用理论模型和有限元法计算出2种不同拼焊板临界板厚比。比较2种方法获得的临界板厚比，误差分别为7.76%和6.15%，处于可接受范围。结果表明，所建立的临界板厚比解析模型是合理的，能有效预测拼焊板变形过程中的失效模式。

英文摘要:

Abstract: Tailor welded blanks (TWB's) consist of steel sheets with different materials, thickness, and coating welded into a single flat blank prior to forming in order to meet the different needs for various positions of parts. TWB's provide various advantages, namely, reduction of weight, fuel consumption and air pollution, lower manufacturing costs, and improved structural integrity over conventional sheet metal forming methods. However, the degradation of TWB's formability causes current applications to be limited. In order to take advantage of these benefits, we need to understand the characteristics related to TWB's forming, and especially be able to predict the failure modes during the press forming.Some important factors which influence the failure modes of the TWB's are: the thickness ratio, the base materials combination and the weld properties. To simplify calculation, in the current investigation, the TWB's with similar materials and different thicknesses were considered to study the effect of the thickness ratio on the failure modes. We created a biaxial stretching model consisting of the weld region, the thicker and thinner sides, and further assumed that the strain was equal along the weld direction. The North American Deep Drawing Research Group (NADDRG) model was used to evaluate the formability of the base materials and the weld. The deformation coordinate relationship among the weld element and the adjacent thinner side element at the dangerous point was modeled analytically based on the statistical mechanical theory. The Ludwick-Hollomon power law was employed to characterize the strain-hardening behavior of the base material and the weld. During calculations, thickness average of thinner and thicker sheets was assumed as weld zone thickness. Then a so-called model of critical thickness ratio (CTR) was presented by the analytical method to predict the failure mode of tailor welded blanks (TWB's) during forming. The model demonstrates that the rupture occurs simultaneously at the weld and the thinner side when the weld properties, the base material properties, and the initial thickness ratio meet CTR model. Other parameters keep constant in the CTR model, only the effect of the thickness ratio on the failure modes was considered in this study. If the thickness ratio exceeds CTR, the rupture occurs at the thinner side; otherwise, the rupture occurs at the weld.To verify the effectiveness of the developed CTR model, we carried out the limit bulging height tests for the TWB's with dissimilar thickness combinations by finite element and experimental methods. The laser TWB's with the base material of DC56D+Z used in experiments were provided by Baosteel Co., Ltd. Tensile tests according to GB/T 228-2002 standards were used to determine the mechanical properties of the base sheets, while miniature samples were used to acquire the mechanical properties of the weld, of which the width was identified by executing the hardness tests. It can also be seen from the hardness analysis results, micro-hardness is not uniformly distributed along the cross-section of TWB's, which reflects the difference in material hardening behavior across the weld lines. The hardness of the weld metal is higher than that of the HAZ and the base metal. The weld width was approximately estimated at 1.5mm.According to the analytical model of the CTR, it is necessary to give the strain state of TWB's before the CTR is calculated. The biaxial tension with equal displacements was considered in the investigation. The deformation of the weld was much less than the base material of TWB's in the direction perpendicular to the weld line. We can exclude the effect of the deformation of the weld on the global deformation. The deformation compatibility relationships between the base sheets were only considered in the direction perpendicular to the weld line. The deformations in the two directions parallel and perpendicular to the weld line were equal based on the hypothesis of the biaxial tension with equal displacements. Then, the strain state of the biaxial tension with equal displacements can be determined. Two approaches, excluding and including the weld properties, was used to model the weld of TWB's in the finite element analysis. The failure always occurs at the thinner side of TWB's when modeling the weld using the former method. It occurs at the thinner side when the thickness ratio is large or at the weld when the thickness ratio is small if modeling the weld using the latter method. Comparing the results from the two methods, we can capture the CTR of TWB's.Given the equiaxial strain state, in the case of two TWB's recommended in the published literatures, the critical thickness ratio was achieved through the analytical and FE method. From the comparison of the two results, there were errors between the analytical and FE results, 7.76% and 6.15% respectively, which attributes to the deviation of the strain state in FE analysis from the equiaxial strain state. The results show the presented CTR analytical model is effective and can predict the failure mode of TWB's in the forming process.

主办单位：中国农业工程学会 单位地址：北京朝阳区麦子店街41号

服务热线：010－65929451 传真：010－65929451 邮编：100125 Email：tcsae@tcsae.org