

Investigation of the Effects of Single Blowhole Size and Through-Thickness Location on Stress State in Aluminum Alloy Welded Joints

Sogo Takuno ¹⁾ Eita Niisato ¹⁾ Kazumi Otake ¹⁾ Sugai Tomotaka ¹⁾ Nishikawa Koji ¹⁾

¹⁾ Toyota Motor Corporation

1 Toyotacho, Toyota, Aichi 471-8571, Japan (E-mail: sohgo_takuno@mail.toyota.co.jp)

KEY WORDS: production • manufacture, quality control, welding Aluminum alloy welded joint, Blowhole defect (D4)

In recent years, the application of aluminum alloys in automotive body structures has expanded in response to the increasing demand for vehicle lightweighting. However, internal welding defects such as blowholes can lead to a reduction in joint strength, making it important to properly understand and assess their influence. Previous studies have mainly focused on the relationship between defect size or porosity and joint strength, whereas the effects of defect location have not been sufficiently clarified. Therefore, this study investigated the effects of the size and through-thickness location of a single blowhole on the stress state and strength characteristics of aluminum alloy lap joints. Finite element analysis was conducted on fillet-welded lap joints. Blowhole diameter, blowhole location, weld leg length, and throat thickness were defined as design variables, and the resulting stress states were analyzed. A surrogate model based on Gaussian Process Regression (GPR) was then developed using the analysis results as training data. Based on the trained model, regions where the predicted strength fell below that of a reference weld bead were identified as the Strength Impact Region, enabling visualization of the combined effects of blowhole size and location on joint strength. The analytical results revealed that the through-thickness location of a blowhole had a greater influence on the stress state than its size. In particular, when a blowhole was located near the weld root, stress concentration increased significantly, resulting in a marked reduction in strength. Furthermore, by simultaneously considering blowhole size and location, it became possible to quantitatively identify regions where strength degradation is likely to occur. To validate the machine learning predictions, static tensile tests and fatigue tests were conducted using specimens containing artificial defects. The experimental results showed that, in static testing, the maximum load decreased when the defect was located close to the weld root. Similarly, fatigue testing demonstrated a reduction in fatigue life for defects positioned near the crack initiation site. In addition, for a given defect location, larger defect diameters resulted in lower strength. These experimental observations were in good agreement with the machine learning predictions, confirming that the proposed Strength Impact Region appropriately represents the influence of blowholes on joint strength. The findings of this study demonstrate that not only blowhole size but also through-thickness location must be considered when evaluating the strength of aluminum alloy lap-welded joints. In addition, the combination of finite element analysis and machine learning was shown to be an effective approach for visualizing the strength impact region of blowhole defects. The proposed method has the potential to support welding quality assessment and the establishment of rational defect acceptance criteria.

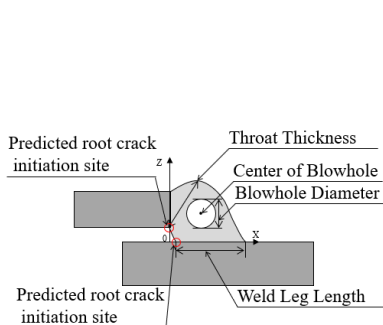


Fig.1 Cross-Section of a Lap Joint

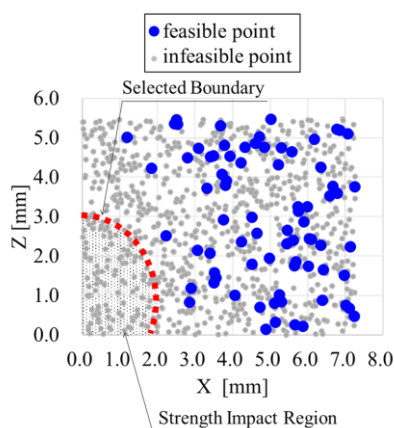


Fig.2 Strength Impact Region and Selected Boundary

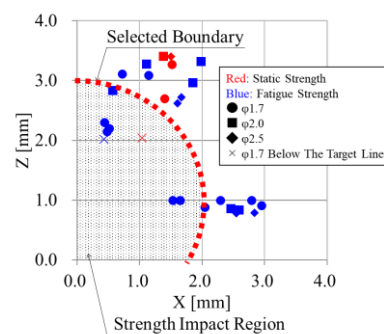


Fig.3 Comparison of Machine Learning Predictions and Experimental Results