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Improvement of joinability in a hole clinching process with aluminum alloy and carbon fiber reinforced plastic using a spring die

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Abstract
Hole clinching is a method for joining carbon fiber reinforced plastic (CFRP) and ductile materials. Previously, in conventional hole clinching, the joinability of CFRP and ductile materials was limited by the ductility of deformed materials, and damages to CFRP laminates. In this study, a new type of hole clinching tool called a spring die is proposed. This tool is designed to improve the joinability of materials in a hole clinching process using CFRP and aluminum alloy (AA5083). In spring die hole clinching, two pads supported by a coil spring are employed to improve the formability of ductile materials and to reduce damages to CFRP laminates by increasing the compressive hydrostatic stress during the hole clinching process. The effects of compressive hydrostatic stress on joinability in the hole clinching process were evaluated by FE-analysis and experiments. Finally, a single lap shear test was carried out to verify the applicability of hole clinching for joining CFRP and aluminum alloy.

Keywords: *Hole Clinching, Spring Die, Multi-material Design, Joint Strength, Geometrical Interlocking, Joinability*

1. Introduction

As multi-material design concept bodies are widely used in the automotive industry, joining technology is important for assembling components made of dissimilar materials. In particular, the use of carbon fiber-reinforced plastic (CFRP), commonly used for applications in lightweight car bodies, requires a new joining technology to replace resistance spot welding, which is the most common joining method used in automotive assembly lines [1-3]. A number of joining methods for CFRP applications, such as friction stir welding, bonding, and riveting, have been studied in the literature for production of multi-material design concept car bodies [4-9].

Recently, mechanical clinching has emerged as a remarkable technique for metal/non-metal joining, because of its low cost and high-speed fastening. The basic principle of mechanical clinching process is to create the geometrical interlocking between two sheets with the localized plastic deformation by punch and die. The joinability of mechanical clinching process is one of main issues for metal/non-metal joining in practice. Abe et al. [10] have studied the suitability of clinching for joining high-strength steel alloys. Lambiase and Di Ilio [11] have showed that the ductility of joined materials were a critical factor to determine the joinability of mechanical clinching process by experimental and numerical damage analysis.

There are two approaches to improve the joinability of clinching process. One is to improve the ductility of joined materials by employing the heating technique at joints. Lambiase and Di Ilio [12] have investigated the joinability of metal/polymer in a mechanical clinching technique involving preheating. The influence of joining temperature on the joinability have been studied by Lambiase et al. [13, 14]. Osten et al. [15] have locally heated the joint by means of short-time laser heating to soften the joined materials. Abibe et al. [16] have developed an injection clinching joining process for polymer-metal hybrid structures. Gude et al. [17] have proposed a new clinching process, called "thermoclinching", for joining textile-reinforced thermoplastics and metallic components. These studies showed that clinching processes were applicable to metal/non-metal joining, although their applicability was limited by the ductility of non-metallic materials.

The other approach is to develop the new clinching technique to reduce the ductile damage at joint. Abe et al. [18] have inserted a rubber ring in clinching die to give counter pressure to lower sheet. He et al. [19, 20] have applied extensible die to mechanical clinching process. The effectiveness of extensible die on the joinability have investigated by Lambiase et al. [21-23]. According theses studies, the joinability can be improved by controlling material flow and developing the hydrostatic stress in deformed materials during clinching process. Also, these techniques showed some advantages, such as saving energy and production time, compared to mechanical clinching with heating source.

Lambiase and Ko [24, 25] have showed the feasibility of new mechanical clinching technique for joining

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