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Impact compressive behavior of deep-drawn cups consisting of aluminum/duralumin multi-layered graded structures

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ABSTRACT

This study aims to investigate impact compressive behavior of deep-drawn cups consisting of aluminum (A1050)/duralumin (A2017) multi-layered structures, which are fabricated by hot rolling. Such multi-layered structures are possibly used for a new type of crash boxes in automobiles to effectively absorb impact energy. The effect of heat treatments on micro-Vickers hardness gradients at the interfaces between layers in 2 and 6-layered aluminum/duralumin structures have been investigated. Impact compressive behavior of deep-drawn cups consisting of such aluminum/duralumin multi-layered graded structures has been studied in terms of energy absorption, maximum force and maximum displacement with examination based on micro-Vickers hardness results. Deep-drawn cups consisting of 6-layerd clad structures with gradient properties exhibited superior impact compressive characteristics to be effective in application to vehicle crash absorbers.

1. Introduction

Safety of vehicles mostly depends on behavior of frontal automotive structures during crash. These structures, which are defined as crash boxes, are main energy absorbers for crash. Crashworthiness of crash boxes is mainly determined by their dimensions and materials. They can be designed for effective absorption of energy generated during crash, which contribute to reduce injury of car passengers and the damage of car in various speed collisions [1]. Conventionally, the car crash box have been made from homogeneous, aluminum alloy, magnesium alloy, steel, and plastic resin as well as its composites [2–5].

Impact energy absorption in metallic crash boxes normally proceeds by progressive buckling and local bending collapse of columns wall. Aluminum foams also have been attracting interest with their potential to deliver good performance such as low weight, high specific stiffness and strength, and good energy absorption [6–9]. These features make metallic foams the potential material for absorbing impact energy during the vehicular crash. In comparison to metal forms, composites including fiber reinforced plastics (FRP) crush in a brittle manner and they fail through a sequence of fracture mechanism involving fiber fracture, matrix crazing and cracking, fiber-matrix debonding, delamination and internal ply separation. The high strength to weight and stiffness to weight ratios of composite materials motivated the automobile industry to gradual replacement of the metallic structures by composite ones [10–14]. Recently the application of aluminum alloy-based clad materials to crash boxes in automobiles has been proposed with a new concept of functionally graded materials (FGMs) [15,16].

Multi-layered structures possess various properties, which surpass those of single metal sheets. Most multi-layered structures not only preserve the original characteristics of the individual layer metals but also provide additional functional properties [17,18]. Highly functional compound multi-layered sheets including sandwich sheets have been widely manufactured for increasing industrial needs. Generally, with different material combinations, multi-layered structures can have advantageous characteristics such as good thermal conductivity, anti-corrosion properties, wear resistance, surface quality and so forth.

FGMs are advanced multi-phase composite structures that are engineered to have a smooth spatial variation of material constituents, microstructures, properties and others. This variation results in an inhomogeneous structure with smoothly varying thermal and mechanical properties. The advantages of FGMs as an alternative to two dissimilar materials (ceramics and metal) joined directly together include smoothing of thermal stress distributions across the layers, minimization or elimination of stress concentrations and singularities at the interface corners and increase in bonding strength [19–21]. Multifunctional inhomogeneous materials such as FGMs have been considered to be effectively used in automotive crash boxes.

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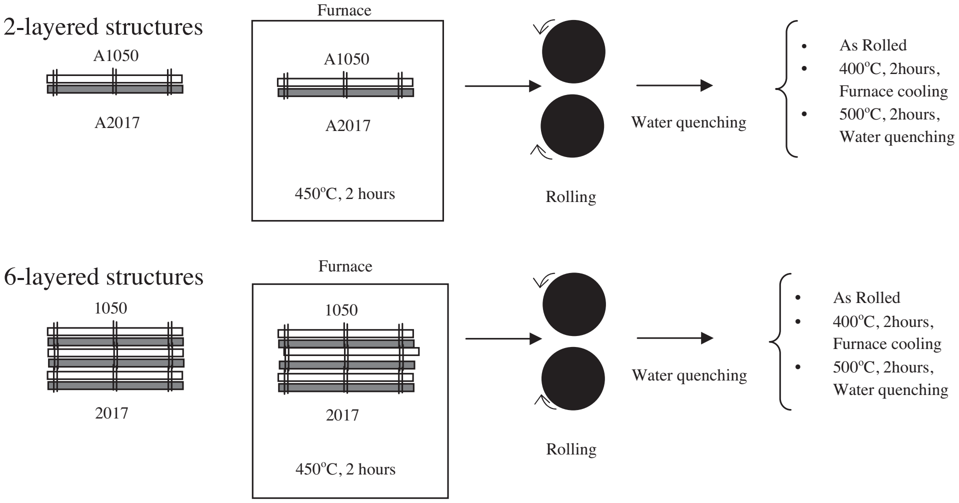

Fig. 1. Hot rolling joining processes of 2-layered and 6-layered structures.

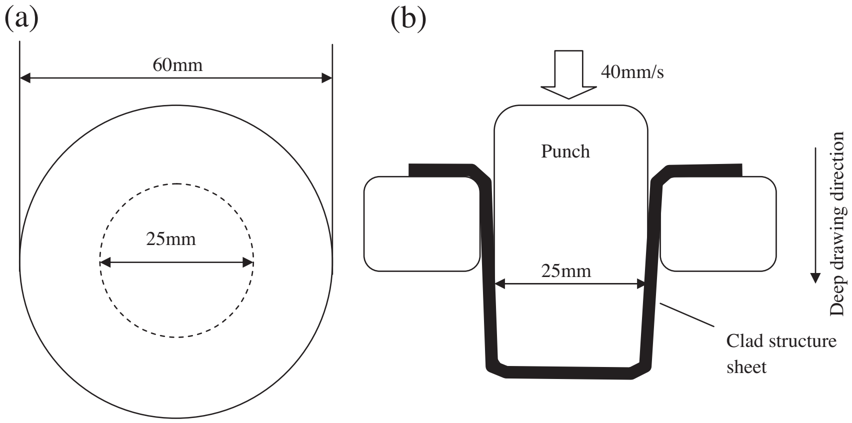

Fig. 2. Schematic illustration for deep drawing processes.
(a) Aluminium/duralumin multi-layered sheet for deep-drowning.
(b) Set-up for deep drawing (including a die)

For impact behavior of crash boxes, numerical and experimental studies have been made so far [22,23]. A classical analysis of plastic folding behavior of a thin cylindrical shell under axial impact loading conditions goes back to the work of Alexander in 1960 [24]. A theoretical study on the plastic deformation of a prismatic column subject to static compression load was conducted by Wierzbicki and Abramowicz [25], whose validity was verified by experimental work by Abramowicz and Jones [26]. In their work, they also examined the dynamic crushing strength of columns. For a specific material, complete static and dynamic axial crushing tests of square thin-walled aluminum extrusion were conducted by Langseth et al. [27].

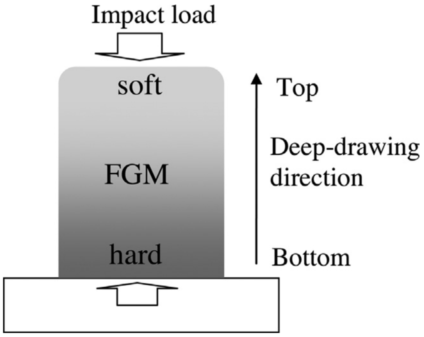

Fig. 3. Schematic illustration of macroscopically functional gradient in a deep drawn cup.

In this study, the effect of heat treatments on micro-hardness distribution at the layer interface and deep-drawing formability of 2 and 6-layered aluminum/duralumin structures and impact compressive behavior of the cups consisting of these multi-layered structures have been investigated. Impact compressive behavior of deep-drawn cups with micro- and macro-scale functional gradient of composition and properties has been investigated in terms of energy absorption, maximum force and maximum displacement. Relation between micro-scale mechanical properties of multi-layered sheets and macroscopic deformation of their deep-drawn cups consisting has been examined to produce superior crash absorbers.

Table 1
Sample descriptions of 2- and 6-layered structures.

2LAR	As-rolled (no heat treatment) 2-layered structures
2LHT400	400 °C heat-treated 2-layered structures
2LHT500	500 °C heat-treated 2-layered structures
6LAR	As-rolled (no heat treatment) 6-layered structures
6LHT400	400 °C heat-treated 6-layered structures
6LHT500	500 °C heat-treated 6-layered structures