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Technical Paper

Friction assisted joining of aluminum and PVC sheets

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ABSTRACT

The present study is aimed at investigating the influence of the main process parameters on the mechanical behavior and morphology of friction assisted joints made on aluminum and PVC sheets. To ensure the successful achievement of the joint, the aluminum sheets were pre-treated by means of laser texturing process. Thus, an instrumented prototypal apparatus was developed to produce these joints under load control. The main process parameters were, the plunging load and dwell time. Mechanical characterization of the joints was performed by means of single lap shear tests. In addition, morphological analysis was performed by means of optical Microscopy and Scanning Electron Microscopy to evaluate the dimension of the joined area as well as to evaluate the possible degradation of the polymer. Infrared analysis was also performed to evaluate the variation and distribution of temperature during the joining process. According to the achieved results, the maximum shear strength (16 MPa) was reached (that is 75% of the shear strength of the base material) by the employment of the maximum plunging load with an interaction time of 20 s. Higher dwell time resulted in development of material degradation with consequent reduction in the joints strength.

1. Introduction

Nowadays, multi-materials assemblies are widely employed into an increasing number of applications to exploit their different characteristics e.g. mechanical, thermal and physical behavior as well as aesthetical appearance. Because of the great difference among metals, polymers and composite materials, the adoption of the proper joining process is often a challenging issue to conciliate different requirements including mechanical behavior, productivity, low environmental impact, cost, automation, etc. For this purpose, adhesive bonding and mechanical joining processes are often adopted. Adhesive bonding enables lower stress concentration (because of the absence of holes and spot joints), lower increase in structure weight, good corrosion resistance and excellent aesthetical appearance (because the joint is not visible). Nevertheless, adhesive bonding requires extensive surface preparation (which often involves solvents), long processing time (due to preparation of substrate and curing time), employment of specialized workers and high environmental impact (due to the employment of solvents and emission of volatile compounds) [1]. In addition, adhesive bonds are highly sensible to environmental agents (such as moisture), temperature, bonding technique, adhesive layer thickness as well as the presence of local gaps between the substrates that should be controlled with great care [2].

Because of such problems, mechanical joints are commonly preferred to adhesive bonds in highly critical and safety rated components, such as aircraft frames, automotive, etc. [2]. Generally, mechanical joining processes involve external components such as screws or rivets that determine an increase in structure weight, additional costs and require predrilled holes, which come with an increase in the overall manufacturing cycle time [3]. However, the cycle time can be dramatically reduced by the employment of hole punching instead of common drilling even on composite laminates [4] or the employment of fast mechanical joining processes such as self-pierce riveting SPR [5] and mechanical clinching MC [6,7]. Both these processes are suitable to join metals sheet with thermoplastics [8] as well as composite materials [9–11].

Besides MC and SPR, new joining processes have been developed in the recent years to produce hybrid structures involving metals and polymers or composite laminates, including Friction Stir Welding [12], Laser-Assisted Direct Joining (LADJ) [13–15], Friction Lap Welding (FLW) [16–18], Friction Spot Joining (FSJ) [19–21], friction riveting [22,23], friction based stacking [24,25], and ultrasonic spot welding [26]. In this processes, mechanical fastening and physical/chemical bonding between the substrates are produced between the metal and the polymer. This enables to

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Table 1
Main mechanical properties of the materials.

Material	Young Modulus [GPa]	Yield Strength $\sigma_{y0.2}$ [MPa]	Tensile Strength, σ_{max} [MPa]	Elongation at rupture [%]	Start of Degradation Temperature [°C]	Melting Point [°C]
AA5053	67	100	250	15		
PVC	2.8		37	2	293	> 210 [54]

overcome almost all limitations involved in adhesive bonding, e.g. most of these processes do not require extensive pre-treatment of the substrates, involve low cycle time and lower production of fumes (absence of solvents for cleaning), and they are characterized by greater process robustness. For these reasons, LADJ has been employed to join a number of materials including PET-AISI304 [27], PET-titanium [28–32], PMMA-AISI304 [33,34], Polytetrafluoroethylene (PTFE)-titanium [35], PET-aluminum [36], ABS-zinc-coated steel [13], PC-AISI304 [37] as well as to join fiber-reinforced thermoplastics (PC, PA66, PE) [38–40]) as well as Carbon Fiber Reinforced Plastics CFRP [41–43]. On the other hand, FLW and FSJ have been successfully employed for joining metal to thermoplastic materials [17,18,44] and has been extended to join Carbon Fiber Reinforced Polymer (with thermoplastic matrix) to aluminum [16,19–21,45–47].

To improve the mechanical strength of the joint, the metal sheet surface can be treated e.g., when dealing with aluminum sheets anodization has demonstrated to improve the adhesion with thermoplastics [36] or even texturing. In the latter case, dramatic increase in the mechanical behavior of the joints were observed [48–51].

In the present investigation, Al-Mg sheets were joined to Polyvinyl chloride (PVC) sheets by means of Friction Assisted Joining FAJ process. An integrated approach involving loads measurement, IR thermal analysis, morphological and mechanical characterization of the joints was followed. Since the poor chemical affinity of these two materials (the strength of the joints made without pretreating the aluminum and PVC sheets were lower than 0.2 MPa), laser texturing was performed on aluminum sheets before friction assisted joining. The joining tests were conducted on a prototypal CNC drilling machine by varying the plunging force and the dwell time. Single lap shear tests were conducted to evaluate the influence of the processing parameters on the mechanical behavior of the joints performed under different processing conditions. Therefore, morphological analysis was conducted to understand the main phenomena occurring during the joining process. To this end, both Optical Microscopy (OM) and Scanning Electron Microscopy (SEM) were involved in the study.

2. Materials and methods

Aluminum alloy AA5053 sheets with 2 mm of thickness were joined to polyvinyl chloride (PVC) with 4 mm of thickness. These materials are often coupled for production of windows frames for civil applications. Mechanical characterization of the base material was performed by conducting tensile tests according to ASTM E08 [52] and ASTM D638 [53] (Type 4) standards for the aluminum and PVC, respectively. In addition, Thermogravimetric analysis (TGA) was conducted to determine the degradation temperature. To this end, a Thermogravimetric Analyzer model L81/1550 by LINSEIS was adopted with a heating rate of (40 °C min^{-1}). The main mechanical properties of the materials are summarized in Table 1.

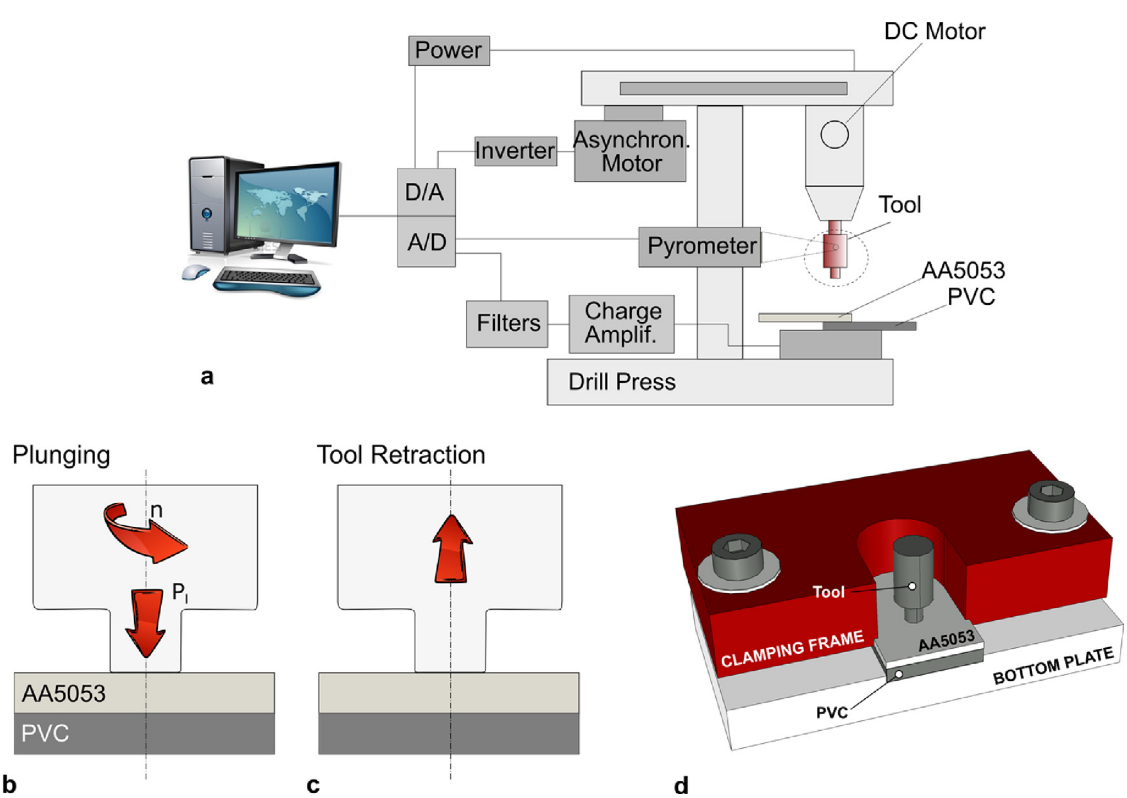

Fig. 1. (a) Schematic representation of the adopted CNC instrumented machine, (b) plunging (c) retraction phases and (d) schematic of the clamping frame.