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An experimental study on clinched joints realized with different dies

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ABSTRACT

An experimental investigation has been conducted on mechanically clinched joints, produced with fixed and extensible dies with different forming forces. Mechanical testing involving single lap shear tests, both with one and two joining points, and peeling tests were conducted under quasi-static conditions to assess the different mechanical behaviors of these joints. The effect of the processing conditions on the main mechanical response of the joints, namely the maximum strength, stiffness and absorbed energy, was investigated.

The results showed that the joints produced with the extensible die exhibited a similar strength as compared to those produced with the fixed die in single lap shear tests, while they are characterized by a higher strength (up to 40%) when loaded during the peeling test because of a larger interlock. In addition, the employment of extensible dies allows a drastic reduction of the forming loads as compared to those required by adopting the fixed dies.

1. Introduction

The mechanical fastening of thin structures is receiving considerable attention since it has the possibility of overcoming several problems concerning welding processes. Indeed, the increasing employment of high specific strength materials, such as aluminum alloys and high strength steels, in the automotive and aerospace fields and the difficulty in welding aluminum components, due to the natural presence of surface oxide layers, high conductivity and low melting point, has induced investigations into new fastening processes, generally based on mechanical joining. Conventional mechanical fastening processes requiring a predrilled hole are unsuitable for the automotive industry because of the high run time. Thus, self-pierce riveting and mechanical clinching are being more and more employed in order to reduce the fastening time of sheet components.

In mechanical clinching, the sheets are connected without the employment of subsidiary material but rather by generating a mechanical interlock between the sheets. The relatively simplicity of clinching tools, low cost of the machines, cleanness of the process, absence of surfaces pre-treatments, cleaning requirements as well as the reduced processing time (which is almost 1 s) represent the main benefits over competitive processes. Driven by such advantages, mechanical clinching has been also applied to relatively thick plates [1] and it has been extended to materials other than metals [2–4]. In order to improve the mechanical strength of clinched connections, clinching tools should be designed to produce high values of interlocks (between the sheets) without excessively reducing the neck thickness of the punch-sided sheet. In order to perform the tools optimization and increase the process robustness, FE models represent a viable solution [5].

Extensive literature on the static and dynamic strength of clinched joints has been produced [6–11]. The main joint failure mechanisms have been established in [12] while an analytical model to predict the mechanical strength of clinched joints during tensile tests on H-type specimens was proposed in [13]. The effect of process parameters has been intensively investigated to increase the clinched joints' strength produced with fixed [13,14] as well as extensible dies [15–17]. Because of the complex material flow during the joining operations, a series of studies has been carried with FE models [6,8,18,19] and optimization approaches have been developed for the automatic design of clinching tools [20–22]. Recent developments in employment of FE models to clinching processing deal with the prediction of the damage initiation and evolution in clinched connections [23,24], the improvement of the clinched connection quality by reducing the protrusion depth [25] and even the optimization of the machine design [26] to achieve the desired rigidity.

The aim of the current study is to experimentally assess the influence of the processing conditions and die type on the joint strength, the failure mode, the stiffness and the energy absorbed. Different mechanical tests were developed including single lap shear tests with one and two joints and peeling tests. The different failure modes arising in the tests were correlated to the geometry

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of the clinched joint according to the different processing conditions. In order to analyze the strain localization during the tests, a digital image correlation (DIC) technique was also employed.

The results show that the mechanical properties of clinched joints produced with extensible dies have a similar strength to that of joints produced with fixed dies during shear tests. Conversely, clinched joints produced with extensible dies exhibit a superior strength and absorb more energy than the joints produced with fixed dies when subjected to peeling forces. The results also showed that a lower forming force is required to join the sheet when extensible dies are employed.

Table 1
Mechanical properties of AISI 1005.

E [GPa]	$R_{p0.2}$ [MPa]	R_m [MPa]	E_{tot} [%]
203	167	307	33

Table 2
Chemical composition of AISI 1005.

C [%]	Mn [%]	P [%]	S [%]	Fe [%]
0.05	0.3	0.035	0.05	Remain

2. Materials and methods

2.1. Clinching tests

Experimental tests of clinch joining were performed on low-carbon steel AISI 1005 sheets with nominal thickness $t=1.0$ mm. The mechanical behaviors (measured from uniaxial tensile tests) and the chemical composition of the analyzed material are summarized in Tables 1 and 2, respectively.

The samples used for clinching tests were cut from a unique sheet. Clinching tests were performed using a portable JURADO machine, model Python, which can supply up to 30 kN. An extensible die and fixed dies were investigated, the former is a conventional extensible die supplied with the clinching machine which is suitable for ductile metals while the fixed dies were designed by the authors and produced by CAMS (Chieti, Italy). The three fixed dies have different shoulder diameters, while all the other characteristics are almost identical to the extensible die geometry. The diameter of the fixed dies ranges within the minimum diameter (before joining) and the maximum diameter (after joining) assumed by the extensible die. Indeed, the smaller die (FD1) has a diameter $D=6.1$ mm, which is a little larger than that of the extensible die before clinching. The larger die (FD3) has a diameter $D=6.7$ mm which produces a similar punch–die cavity volume to the extensible die when the joint is produced with the maximum load of 30 kN. In addition a further fixed die (FD2), having an intermediate diameter $D=6.4$ mm, was employed. The geometrical dimensions of the clinching tools are represented in Fig. 1.

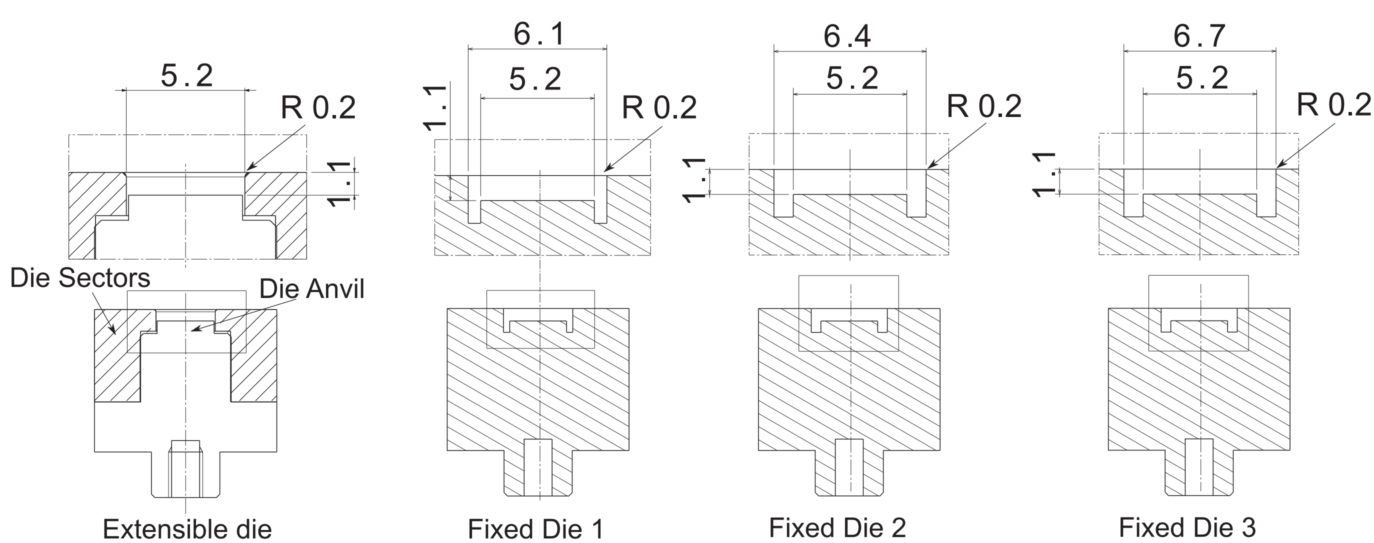

Fig. 1. Schematic of clinching tools with extensible and fixed dies.

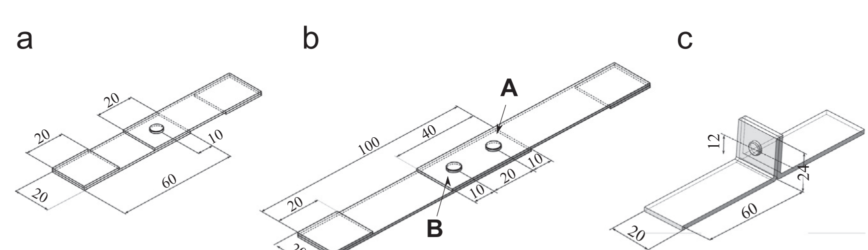

Fig. 2. Schematic of (a) single lap shear sample with one joint, (b) single lap shear sample with two joints and (c) peeling sample with one joint.