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Experimental tests on pure aluminium shear panels with welded stiffeners

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Abstract

Pure aluminium is an innovative material recently proposed in the field of seismic engineering, due to both low yield strength and high ductility features. Aimed at evaluating the energy dissipation capacity of stiffened pure aluminium shear panels, an experimental investigation has been recently developed. In the current paper the results of two cyclic tests on aluminium panels with welded stiffeners subjected to shear loads are provided. Tested specimens have in-plane dimensions 1500 × 1000 mm, with a thickness of 5 mm and are made of AW 1050A alloy, which is characterised by a high degree of purity (more than 99.50%), also subjected to heat treatment to improve the material's mechanical features. Such a material has been chosen due to its very low yield strength (about 20 MPa after heat treatment), high hardening ratio (about 4) and large ductility (about 40%). Two different configurations of welded stiffeners have been adopted, in order to investigate the effect of plate local slenderness. On the whole, the obtained results pointed out a good structural performance of tested panels, measured in terms of strength, stiffness and dissipative capacity, proving that the proposed system can be usefully employed as a special device for passive seismic protection of new and existing structures.

Keywords: Pure aluminium; Shear panels; Shear buckling; Dissipative devices; Ductility; Cyclic behaviour

1. Introduction

A recent approach in the seismic design of structures is based on the adoption of special seismic protection devices acting as sacrificial elements during seismic events, thus limiting the damage of both structural and non-structural elements. Within metallic yielding-based devices, diagonal bracings and panel systems can be conveniently used with high efficiency.

In the first case, the dissipative function is carried out by either ductile braces [1] or Added Damping And Stiffness (ADAS) elements [2]. Notoriously, in the former category Buckling Inhibited Braces (BIB) and Unbonded Braces are included. They are composed of a steel core, as load-carrying and dissipative element, placed inside a lateral support jacket, so as to obtain a buckling restrained bracing which is able to dissipate energy under both tensile and compression axial forces, providing a stable hysteretic behaviour without any pinching and/or degradation of strength and stiffness up to the system failure. In the latter category, the dissipative system is installed either between the foundation and the structure or between two relevant parts of the structure. The system is differentiated in relation to the shape of the device (for instance X-shaped, E-shaped, U-shaped, Ω-shaped, honeycomb-shaped and so on), as well as for the type of dissipative mechanism on which the system is based (for instance based on flexural, shear, axial and torsional deformations).

When shear panel systems are employed, stiffening, strengthening and dissipative functions are carried out by either the basic plate constituting the panel or by the connecting system between shear panels and the bearing structure [3]. The former solution appears more effective and promising. In fact, firstly, the adopted plates, when rigidly connected to the external frame, may easily provide high in-plane strength and stiffness; secondly, the possibility to have a quite uniform shear stress distribution throughout the plate ensures a large energy dissipation capacity due to the large size of yielding fields.

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Table 1
Mechanical features of typical LYS steel and heat treated pure aluminium EN-AW 1050A

Material	$f_{0.2}$ (N mm^{-2})	f_u (N mm^{-2})	ε_u (%)	E (N mm^{-2})	$E/f_{0.2}$	$\alpha = f_u/f_{0.2}$
LYS steel	86	254	50	210 000	2441	2.95
Heat treated pure aluminium (EN-AW 1050A)	**21.3**	**80**	**45**	**70 000**	**3286**	**3.76**

In order to enhance the dissipative capacity, shear panels should be conceived in order to increase the shear buckling threshold and, in the meantime, to reduce the yielding interstory drift, so to allow the seismic protection of the primary structure also for reduced lateral loads. To this purpose, adequate stiffener configurations must be applied, helping shear panels to provide a pure shear dissipative mechanism with plastic deformations developing before the occurrence of shear buckling. Plate buckling may be more easily controlled when low yield strength metals are adopted. As a consequence, shear panels made of low yield strength materials may be characterised by a very stable hysteretic behaviour up to large deformation levels, with a conspicuous strain-hardening under cyclic loads and with limited strength and stiffness degradation arising from buckling waves. A first solution is represented by the so-called LYSW (Low Yield Shear Walls), which in the last decade has been proposed and adopted mainly in Japan [4]. Also, the use of common aluminium alloys has been proposed to develop new devices for passive protection of structures subjected to seismic and wind loading [5–9].

Actually, an alternative and more effective solution for the fabrication of dissipative shear panels could be based on the use of pure aluminium owing to lower yielding stress and easier availability in the world market. Therefore, a wide experimental campaign to investigate the energy dissipation capacity of aluminium stiffened shear panels has been undertaken at the University of Naples Federico II in cooperation with the University of Chieti-Pescara G. d'Annunzio. Two aluminium alloys have been employed, namely AW 1050A and AW 5154A. The former, also indicated as "pure aluminium", is characterised by a very high degree of purity (99.50% of aluminium), while the latter is an alloy commonly used for the civil engineering applications. The experimental activity is still ongoing and six shear panels, four made of AW 1050A and two made of AW 5154A, have been tested so far [10]. This experimental activity was preceded by a preliminary numerical study based on both static and dynamic inelastic analyses carried out in order to evaluate the seismic performance of steel frames equipped with pure aluminium shear panels [11]. The obtained results clearly showed that these panels provide a useful stiffening effect, a significant energy dissipation contribution and also a remarkable increase of global strength, on the whole increasing the performance of the structural system. These effects allowed a significant global economical advantage, measured in terms of saving of steel weight of the basic structure when compared to the employment of other technical solutions, i.e. the ones based on the use of simple moment resisting steel frames. The economical analysis also considered the major cost related to the employed aluminium for shear panels, which was duly taken into account.

In this paper, the results of two cyclic tests carried out on the AW 1050A aluminium panels are presented. In the following, for each test the obtained cyclic response of the specimen is described and the corresponding experimental behaviour is interpreted by means of synthetic numerical parameters, which are used to evaluate the supplied structural performance in terms of dissipated energy, secant stiffness and plastic strength.

2. The experimental program

2.1. The adopted material

According to the purpose of this study, the selected material is the aluminium alloy AW 1050A, which is characterised by a limited conventional yield strength (about 20 MPa) and large ductility (larger than 40%). It is important to observe that the shear panel specimens, after the fabrication, have been subjected to heat treatment, which aids a further improvement of the mechanical features and is also useful to reduce the residual stresses produced by welding during the fabrication process. In particular, a number of specimens have been submitted to a cycle of heat treatments characterised by different phases with constant temperature, each one having a duration of four hours [9].

In Table 1, the mechanical features of the above heat treated aluminium alloy are shown and are also compared with the ones related to a typical low yield strength (LYS) steel. It is worth noticing that due to the processed heat treatment, the aluminium alloy AW 1050A is very suitable for the application under consideration. In fact, it is characterised by a very high value of the ratio between Young's modulus (E) and the conventional yield strength at 0.2% offset strain (f_{02}), which means a high aptitude to avoid buckling [12].

2.2. Geometry of tested panels

The experimental tests have been carried out on panel specimens measuring 1500 by 1000 mm, with a thickness $t = 5$ mm [10,11,13]. Tested specimens are endowed with longitudinal and transversal open rectangular-shaped stiffeners having a depth of 60 mm and obtained by the same sheeting used for the base shear plate and welded to the base shear plate. In order to reduce the sheeting shape distortion produced by shrinkage, the welds has been subdivided into segments and the ribs have been placed on both sides of the sheeting, therefore balancing the residual strain produced during the welding process.

In the present paper, two different types of panel configuration have been considered, which are characterised by a different geometry of the applied ribs (see Fig. 1). For panel type B, the ribs are placed on both sides of the plate according to square fields with side length $b = 500$ mm. Contrarily, the