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Experimental and Numerical Researches on Aluminium Alloy Systems for Structural Applications in Civil Engineering Fields

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Abstract. Structural research and applications of aluminium structures in civil engineering field have grown extensively in the last decades. Low weight, corrosion resistance, production of special profiles by extrusion and aesthetic quality of the aluminium material, together with the availability of specific and detailed design codes at both Italian (CNR-DT 208/2011) and European (Eurocode 9) level, have furthered such a development.
On the other hand, in recent years, several experimental and numerical researches have been developed in order to improve the comprehension of the structural behaviour of aluminium elements, such as extruded and welded members, connections and joints, special devices, giving an important contribution to the present structural codes.
This paper gives an overview of some of the researches developed recently by the authors which are strictly connected to the design and innovation of aluminium alloy structures. In particular, the behaviour of aluminium alloy members, joints and seismic protection devices is analysed, illustrating the results obtained by the above research programs. They put into evidence interesting aspects that deserve further research activities for improving the present codes on aluminium structures, as well as the high potentiality of the aluminium material to be used as alternative to steel for interesting and convenient applications in structural engineering.

Introduction

From the structural point of view, aluminium and its alloys can be considered as a ‘new’ material. In fact, the first building structures made of aluminium alloy appeared in Europe in the early fifties of the last century, when concrete, masonry and steel were the main materials used for fabricating civil engineering structures.

The physical and mechanical properties of aluminium alloys, which represent a wide family of constructional materials, whose mechanical properties cover the range offered by the common mild steels, are the basic reasons of their success as constructional material [1]. Among the main prerequisites, particular attention must be paid to the following: 1) the high corrosion resistance, which does not require any protection coating, even in aggressive environments; 2) the lightness, producing advantages in weight reduction, even if it is partially offset by the necessity to reduce deformability, which provides a high susceptibility to buckling phenomena; 3) the low susceptibility to brittle fracture, even though particular attention should be paid to those problems where a high ductility is required; 4) the extrusion fabrication process, allowing to produce individually tailored shapes according to the requirements which are designed for; 5) the large choice for the connection systems (bolted, riveted and welded) without any difficulty involved.

On the basis of these preliminary remarks, it is possible to state that aluminium alloys can be economical and competitive in those applications in which full advantage of the above prerequisites is taken.

In this paper, the advantages from using aluminium alloys in some applications in the field of civil engineering are highlighted. In particular, an overview of some of the researches dealing with aluminium alloy members, joints and seismic protection devices, developed recently by the authors and strictly connected to the design and innovation of aluminium alloy structures, is provided, emphasizing the high application potentialities of this material.

Extruded members and joints for roof structures

The use of aluminium alloy extruded profiles can be usefully exploited for the erection of reticular space structures. To this purpose, a special extruded member has been proposed. It is characterised by an extruded cross-section composed by two half-tubes connected each other by means of two plates having the thickness to allow for the nodal plate insertion (see Figure 1).

a) *b)*

Figure 1. 2D (a) and 3D (b) views of the proposed aluminium alloy extruded prototype

A prototype of this bar has been fabricated for being subjected to preliminary tests. The bar was made of EN AW-6060 T6 aluminium alloy, having a mean conventional yield stress $f_{0.2}$ = 192.5 Nmm^{-2} and a mean ultimate stress f_t = 218.4 Nmm^{-2}, the latter corresponding to the ultimate strain ε_t = 10%. The geometrical properties of the specimen are the following: a) the thickness of the tubular surface is 3.5 mm, which is increased up to 7 mm in the central part having a width of 68 mm; b) the external diameter of the tube is 115.5 mm; c) the cross-sectional area is 2280 mm^2; d) the second moment of area is equal to 1.94 x 106 mm^4. Some views of the real specimen are illustrated in Figure 2.

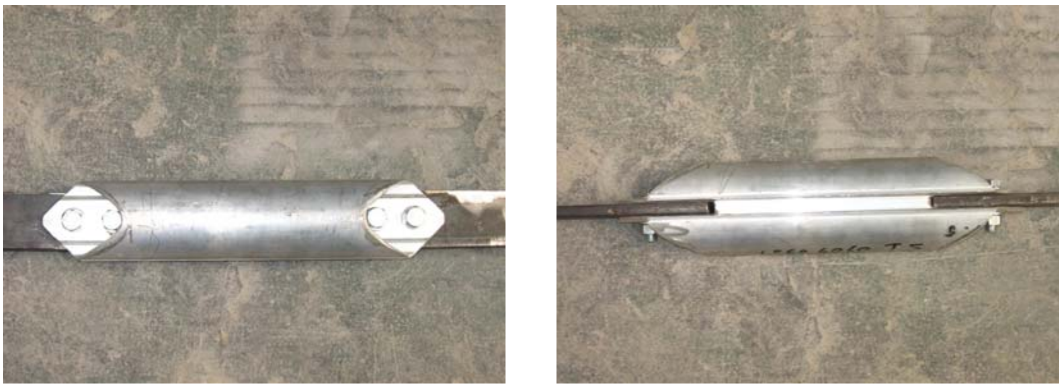

Figure 2. Photos of the EN AW-6060 T6 extruded prototype

The numerical simulation of the tensile test on the prototype bar has been carried out in order to reproduce the experimental behaviour under axial load when it is connected by bolts to the nodal plates. The FEM model has been implemented by the ABAQUS non-linear numerical software. The tubular bar has been modeled by using 3 nodes triangular shell elements having finite membrane strains (type S3) with different base lengths, namely 6, 12 and 24 mm. Geometrical imperfections have been taken into account in the numerical models by assuming an initial bar configuration corresponding to the shape of the first vibration mode with an amplitude equal to half of the specimen thickness. The numerical force-displacement curves for different mesh side lengths are plotted in Figure 3, where an excellent behaviour between the numerical curves and the experimental one is noticed in terms of both maximum strength and stiffness. It is apparent that the best result has been achieved with shell elements having side length of 12 mm, because this solution represents the best compromise between time running and result accuracy.

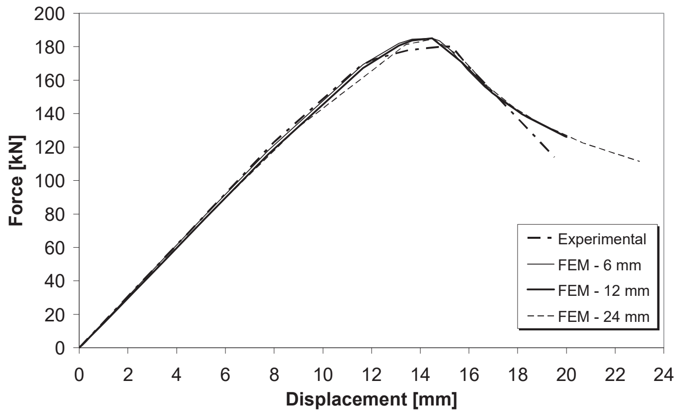

Figure 3. Experimental-numerical comparison for different values of the mesh side length of the proposed aluminium alloy extruded prototype

The effectiveness of the implemented FEM model is confirmed also by the very satisfactory comparison between the real failure mode of the tube and the numerical prediction in terms of stress state, as shown in Figure 4, where the same pattern of fracture lines in both specimens is evidenced. Other information on the examined aluminium alloy components are available in [2].

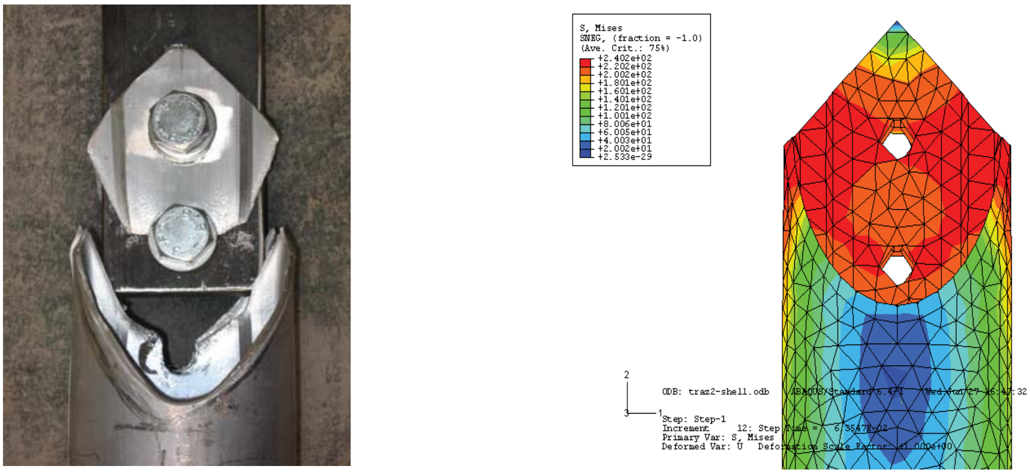

Figure 4. Experimental-numerical comparison in terms of final failure mode

Seismic protection devices

In the framework of the ILVA-IDEM research project, where a full-scale existing r.c. frame was divided into six Structural Units (S. U.) in order to test the effectiveness of different steel-based seismic retrofitting systems, the S.U. n. 5 was chosen to test aluminium shear panels used as special devices to improve the seismic behavior of the existing r.c. frame (Fig. 5a).

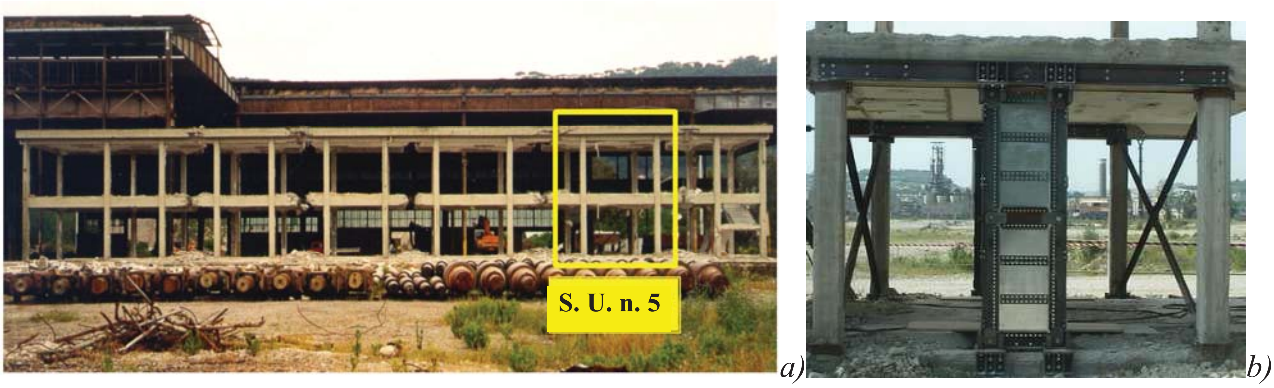

Figure 5. The r.c. structure divided in S.U. (a) and the insertion of aluminium plate shear walls in the S.U. n. 5 (b)

The geometrical configuration of the building portion is characterized by rectangular plan with dimensions of 6.30 x 5.90 m and two floors with heights on the ground of 3.55m and 6.81m, respectively, with roof having variable loads related to maintenance only. The slab thickness is equal to 24 cm and 20 cm for first and second floor, respectively. Both slabs have a middle transversal joist and are supported by emergent rectangular beams placed along the longitudinal direction. In the transverse direction, lateral strength is essentially provided by columns, which have square cross-section with side of 30 cm. The foundation structure is composed by two reverse T-shaped beams placed in longitudinal direction.

A passive control device, having the form of shear panel, for seismic retrofitting of the existing r.c. structures based on a low-yield metal has been applied [3]. In particular, aluminium panels, having a width of 600 mm and a thickness of 5 mm, in the configuration of partial-bay type shear wall, was chosen as seismic retrofitting system (Fig. 5b). The base material herein selected for panels was the pure aluminium, characterized both by a limited strength and a large ductility. Such a material, commercially know as the wrought aluminium alloy EN-AW 1050A, has a degree of purity of 99.50%. To improve its excursions in the plastic field so to represent a suitable passive control system, the aluminium panels after the fabrication, were subjected to a heat treatment to increase of material ductility (up about 40%) and to reduce the yielding stress (to about 20 MPa) [4].

In the experimental test a cyclic loading history under quasi-static conditions and force control with step of 10 kN was applied at the first floor of the r.c. structure. The results of the experimental test in terms of force-first level displacements and final deformed shapes of both the shear panel and the reinforced r.c. structure are reported in Figure 6.

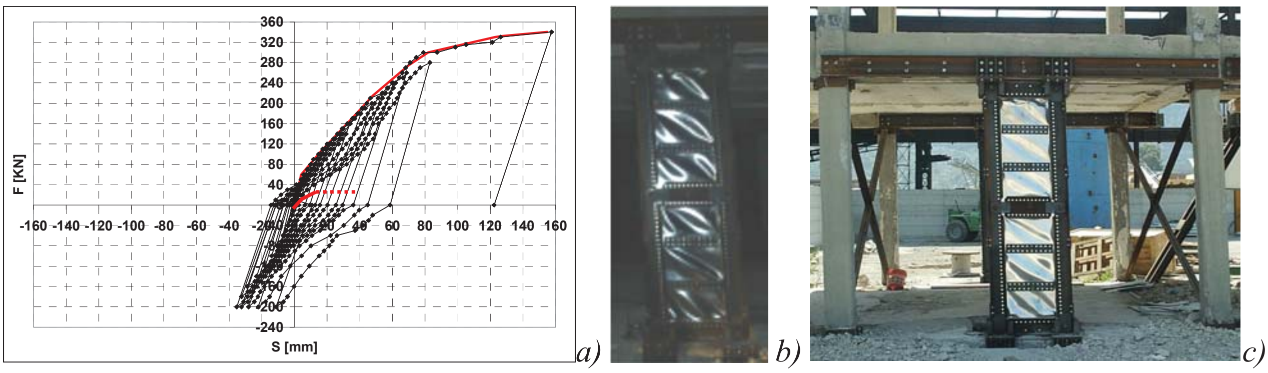

Figure 6. Experimental comparison between the cyclic response of the retrofitted r.c. frame and the monotonic behaviour of the bare r.c. frame (a), the final shape of the aluminium panel (b) and the reinforced structure after the final unloading phase (c)

An initial FEM model of the r.c. structure equipped with aluminium shear panels has been setup by using the SAP2000 analysis program (Fig. 7a). The experimental-numerical comparison of results is depicted in Figure 7b, where it is apparent that the initial FEM model does not simulate very well the experimental curve in terms of stiffness, since some slips occurred at the frame beam-to-column connections. Therefore, appropriate springs with the same stiffness of used bolts have been introduced in the final FEM model in order to simulate the real behavior of the above mentioned joints and, as depicted in Figure 7b, they are able to better interpret the experimental response of the retrofitted structure. It is evident that aluminium shear panels improve significantly the seismic performance of the bare rc framed structure proving the effectiveness of the proposed system (see Fig. 6a), which therefore could be conveniently used to retrofit existing reinforced concrete structures. Major details and information on the developed activity are given in [5].

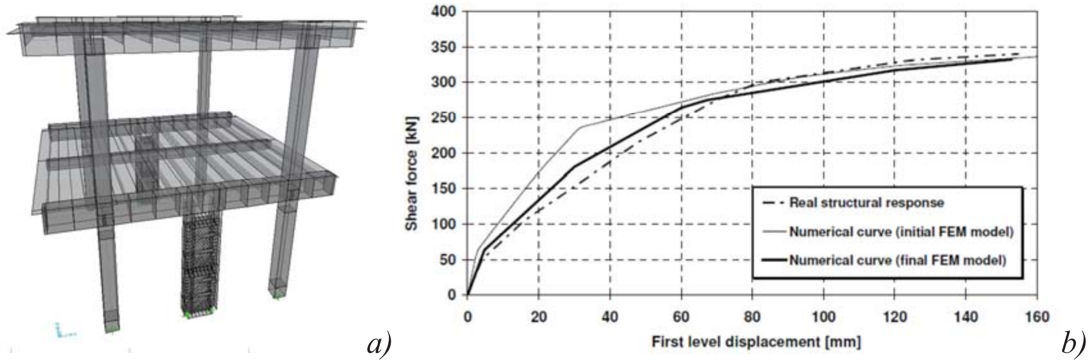

Figure 7. The SAP2000 FEM model of the retrofitted r.c. structure (a) and the experimental-numerical comparison in terms of envelope curve of the cyclic test (b)

T-stub joints

The behaviour of joints in metal structures is very complex and is not simple to be interpreted by means of analytical models. Many activities have been carried out for steel, while only few studies have been developed for aluminium. For this reason, the authors investigated the non linear behavior of bolted aluminium alloy T-stub joints by means of experimental and numerical activities. The tested specimens have been obtained by using plates made of three different heat treated wrought aluminium alloys (EN AW-6061 , EN AW-6082 and EN AW-7020). The joint web and flange plates were firstly obtained from the base sheeting and then assembled among them by means of welded connections. The combination of flange and web elements arising from the three mentioned aluminium alloys allowed the definition of four basic geometrical configurations, each of them subdivided into three subgroups, obtained by varying the flange material, as shown in Figure 8. In addition two different assemblage conditions, namely coupling two T-stub specimens each other and joining a T-stub component with a rigid steel support, were adopted. Then, aiming at investigating the influence of bolts on both stiffness and failure mechanism of aluminium T-stubs, two different configurations (one-bolt and two-bolt row) and three different materials (EN AW-7075 and steel grades 4.8 and 10.9) were considered, in all cases adopting a diameter of 10mm.

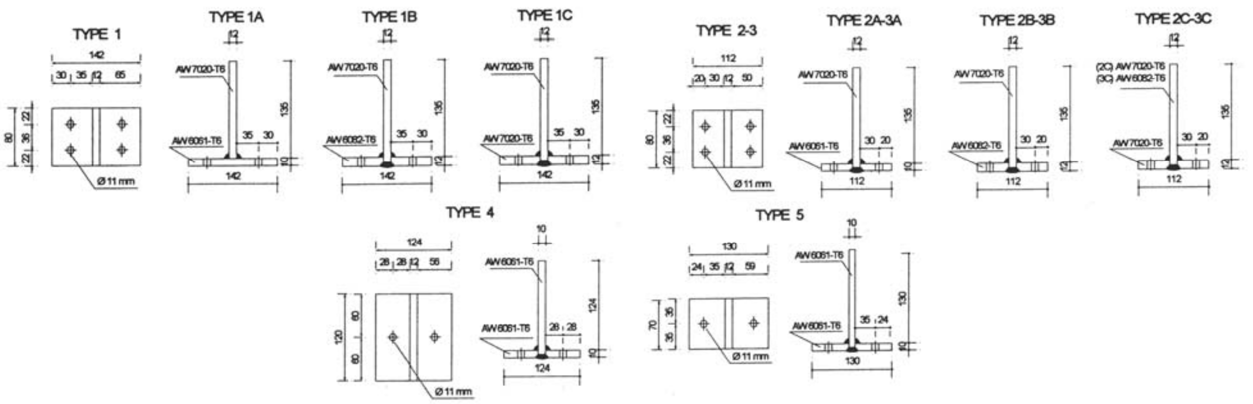

Figure 8. Geometrical configurations of tested aluminium T-stubs

The obtained specimens have been tested in monotonic and cyclic regime, under displacement control. Major details on the experimental tests are available in [6]. Then, FEM models of T-stub joints were implemented with the ABAQUS software in order to simulate the monotonic curves and the achieved Collapse Mechanisms (CM). The results for some specimens are depicted in Figure 9, where a very good experimental-numerical agreement can be observed. Based on such a numerical model, a parametric analysis has been developed in [7], allowing to propose, together with more recent studies [8, 9], the theoretical formulation provided by EC9 to design aluminium T-stubs.

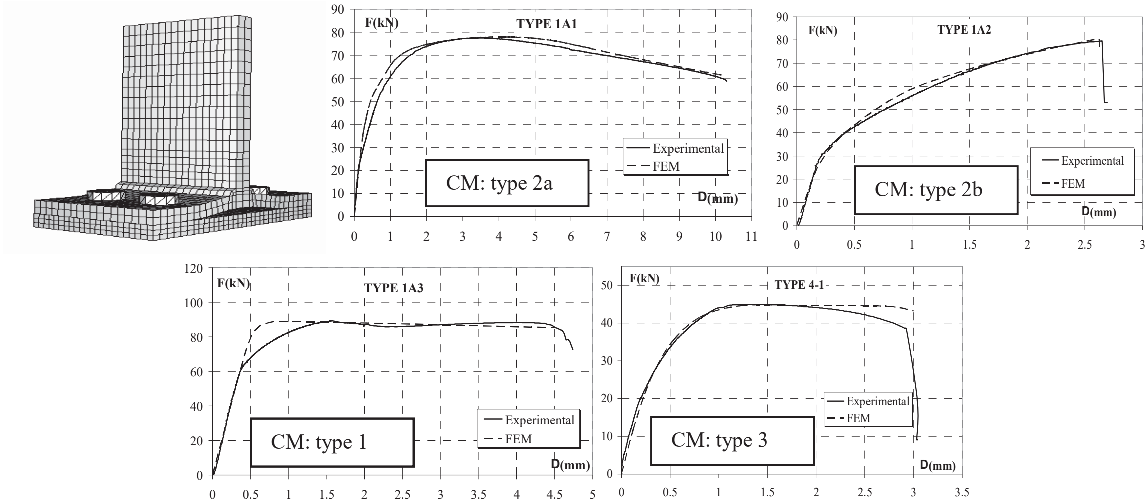

Figure 9. The T-stub FEM model and numerical calibration of some experimental results

Concluding remarks

The investigations herein presented and briefly discussed show the reliability of numerical calculation procedures to predict the complex structural behaviour of examined aluminium structural components. Such results could be also profitably used to improve the existing code on aluminium alloy structures, as well as to promote their use in the civil engineering field.

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