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Experimental study on the mechanical properties of welded-wire meshes for concrete reinforcement in Mexico City

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HIGHLIGHTS

- Mechanical properties of welded-wire meshes (WWW) in Mexico are assessed.
- Parameters are compared to those specified by Mexican and European codes.
- Mechanical properties are proposed for computing stress-strain curves.
- Recommendations for improving test and welding methods are presented.
- Welding procedure can affect significantly to the smaller wires.

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ABSTRACT

Previous experimental studies on the seismic behavior of concrete elements reinforced with welded-wire meshes (WWM) have suggested that WWM do not comply with the mechanical properties specified in Mexican material standards. To thoroughly assess the mechanical properties of WWM available in the Metropolitan Mexico City, an experimental research program was developed. Based on a statistical analysis of measured mechanical properties, main parameters (yield stress and yield strain, ultimate strength and ultimate strain, elongation after fracture, reduction of cross-sectional area, shear strength of welding, and bending capacity) are reported and discussed. Values of the mechanical properties of WWM are proposed for computing stress-strain curves.

1. Introduction

Welded-wire meshes (WWM) made of cold-drawn reinforcement offer significant advantages to the concrete industry; typically, it reduces the cost of steel reinforcement while provides the required steel reinforcement in concrete elements. WWM are used as concrete reinforcement in walls, elevated slabs, slabs on ground, pavements, etc. Several experimental studies have been carried out for assessing the seismic performance of concrete elements reinforced using WWM [1–7]. Some studies have suggested that mechanical properties of this reinforcing material may be lower than the minimum values specified in the corresponding material standards. Results of an experimental research aimed at characterizing the mechanical properties of WWM available in Mexico City and at verifying the compliance with current Mexican standards are reported herein. The mechanical behavior of four WWM types widely used in the construction of concrete structures in Mexico are presented and discussed.

The experimental program comprised tensile, shear at welding, and bending tests. WWW samples come from the five most representative manufacturers in the zone. For each manufacturer, test specimens were obtained from three different production lots. Definition of type, amount and tests method complies with the Mexican (NMX) and American (ASTM) standards. Based on the statistical analysis of the measured mechanical properties, main

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experimental parameters such as yield stress and yield strain, ultimate strength and ultimate strain, elongation after fracture, reduction of cross-sectional area, shear strength of welding and bending capacity, are reported. Measured parameters are compared to the minimum values specified in the Concrete Design Code (NTC-C) in Mexico [8] and Eurocode EC-2 [9]. Consequences in design and seismic performance is discussed.

Results of this study allows, for each type and manufacturer of mesh, the validation of values of elongation after fracture that research studies have reported. Interaction between the number of ruptures at welding zone during tensile tests, and the shear force resisted by the welding is also studied. Stress-strain curves of wires and suitable parameters for characterizing the ductility of the wires are also proposed. Recommendations for improving the standard test methods and the welding procedures are presented, especially those tests related to characterize the ductility capacity of the material. Additionally, values of the mechanical properties of wires are proposed for computing stress-strain curves for code-based design.

2. Behavior of concrete elements reinforced with welded-wire meshes

Previous experimental studies in Mexico [1–3] have evidenced that concrete elements reinforced with WWM have exhibited deformation capacities under seismic load significantly lower than those elements reinforced with low-carbon deformed steel bars. Analysis of tests results of low-rise reinforced concrete walls under seismic shear demands demonstrated that wall displacement capacity was strongly influenced by the brittle behavior of the steel reinforcement used as web reinforcement [1]. During tensile testing of coupons used in such experiment, elongation after fracture of WWM was lower than the minimum values specified by standards. Wire fracture was observed at the welding of perpendicular wires. This finding is an indication that WWM available may be inadequate for the design of reinforced concrete elements subjected to reversed cyclic demands, especially when inelastic behavior is expected. Average stress–strain curves for the two types of web shear reinforcement (4.1 mm WWM and 9.5 mm low-carbon deformed steel bar) measured by Carrillo and Alcocer [1] during tensile tests of coupon specimens are shown in Fig. 1. The tensile strength and strain capacity of the welded-wires and deformed bar are considerably different. Elongation capacity (after fracture) was much smaller in WWM than that of mild-steel reinforcement. The behavior of WWM was characterized by fracture of the material with a slight increment of strain.

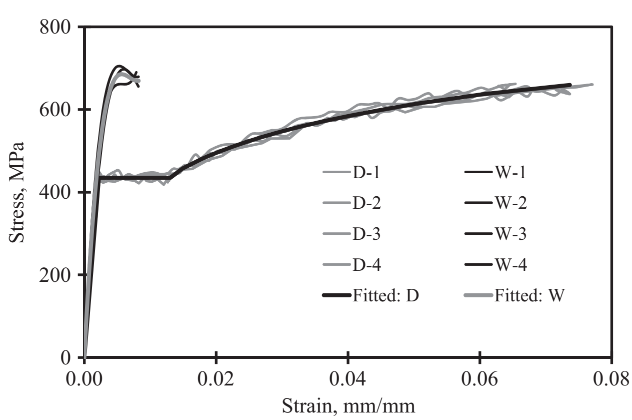

Fig. 1. Typical stress-strain curves of web steel reinforcement: deformed bars (D) and wires of welded-wire meshes (W).

In Canada, Ali-Mirza and MacGregor [4] examined the strength and ductility of one-way simply supported concrete slabs reinforced with WWM. Ali-Mirza and MacGregor [4] observed that the ductility of concrete slabs reinforced with WWM was lower than that reinforced with deformed bars. Riva and Franchi [5] tested a series of 18 cantilever walls made of concrete reinforced with WWM and subjected to cyclic loading. Riva and Franchi [5] argued that cold-drawn WWM were unable to develop the necessary ductility comparable to that required for hot-rolled WWM used in elements that have developed a suitable ductile behavior.

In mild-steel reinforcement, "yielding point" is clearly defined when an increment of tensile strength is not observed while tensile strain increases, thus defining a yielding plateau. In contrast, cold-drawn wire reinforcement such as that in WWM used in the study of Carrillo and Alcocer [1] did not exhibit a specific yield point. In Europe, Bachmann [6] has observed a similar trend in deformed bars having diameters lower than 16 mm. These deformed bars are mostly hot- or cold-rolled in coils and are straightened again when manufactured for the site. The same manufacturing method is used for producing the wires component of WWM, which come from cold-stretching out smooth bars having diameters higher than that of the final wire. Typically, source wires are 6.35 mm (1/4 in.) in diameter.

3. Manufacturing, characteristics and standards for WWM

Welded-wire reinforcement is a prefabricated reinforcement consisting of parallel series of cold-drawn or cold-rolled wire welded together in square or rectangular grids. Each wire intersection is electrically resistance-welded. Pressure and heat fuse the intersecting wire into a theoretically homogeneous section and fix all wires in their proper position. The wire used in WWM is produced from hot-rolled rods. These rods are cold-worked through a series of cassettes to reduce the rod diameter to the specified diameter [10]. The mechanical manufacturing process of the wires used in WWM is depicted in Fig. 2a. In the figure, L_i and d_i are the gage length and the wire diameter before testing. After applying a tensile force F, wire diameter is reduced to a value d_f and the gage length is increased to a value L_f. This procedure causes a shift in the stress-strain curve of the base material. As Bachmann [6] argued, stretching out of the material causes an increment of the conventional yield stress and a reduction of the strain capacity of the material (Fig. 2a). Wires are then welded to make up the mesh. Ahmed [11] tested 48 specimens with different bar diameters for determining the effect of welding in the reinforcing properties. Ahmed [11] reported that strength and elongation of the welded bars decreased by 10–40% and 30–60%, respectively. Therefore, welding of wires may cause crystallization of steel at welded joint, and therefore, it may trigger the fracture in such critical joints.

Minimum values of the parameters for assessing the deformation capacity of wires under tension are shown in Table 1. Minimum values of k (f_u/f_y) and ε_u specified by Eurocode EC-2 [9] are also shown in the table. In addition, minimum mean values of strength of wires and welding specified by NMX B-253 [12] and NMX B-290 [13] standards are included in Table 2. Parameters in the tables are specified by standards related to steel wires for concrete reinforcement. Ductility capacity of cold-drawn wires is commonly assessed through elongation. The elongation is the increase in length of the gage length, expressed as a percentage of the original gage length. Two types of elongation can be measured from a tensile test; "elongation at fracture" is measured during testing using an extensometer with a specific gage length; "elongation after fracture" is measured after testing by fitting the two halves of the broken specimen together and recording the extension of the gage marks. Dove [7] has argued against elongation as an