University of Brescia

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EXPERIMENTAL STUDY ON BOND OF GREASED RIBBED REBARS

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SOMMARIO

1. INTRODUCTION

Ferriera Valsabbia S.p.A. funded a research at the Department of Civil Engineering of the University of Brescia for the experimental study of bond behavior of greased ribbed reinforcing bars (ribbed rebars).

Several European Standards prescribe to determine the bond of a ribbed rebars by means of pull-out tests or beam tests (Plizzari and Franchi, 1996). Both test methods were also recommended by the international associations Rilem, CEB and FIP (Rilem/CEB/FIB, 1979). The bond phenomenon of greased rebars was study by means of pull-out tests, using a special test set-up that better reproduce real loading conditions (Giuriani and Plizzari, 1991).

2. SPECIMEN CONFIGURATION

The experimental specimens were designed in order to simulate the behavior of a rebar anchored in a beam, in the influence zone (Δz) of a stirrup with two arms (Figure 1); the concrete block is been simplified by placing bars anchored in the plane of symmetry AA of the specimen (Figure 2).

The specimen consists of a concrete prism in which was anchored the rebar, arranged along one of the axes of symmetry of the specimen (Figure 2). The ribs of the anchored rebar are arranged so that the maximum radial thrust formed in the direction of the blocks C1 and C2 of the specimen, and then the main splitting crack developed in the plane A-A, not counteracted by the bottom plates of the bench (Figure 2) . The crack formation in that plan was favored also by the presence of two steel angles positioned at the ends of the specimen. These steel angles have also the purpose of redistributing the high compressive stresses that occur in the concrete.

The bond tests were carried out on bars with a diameter (Ø) of 16 and 20 mm.

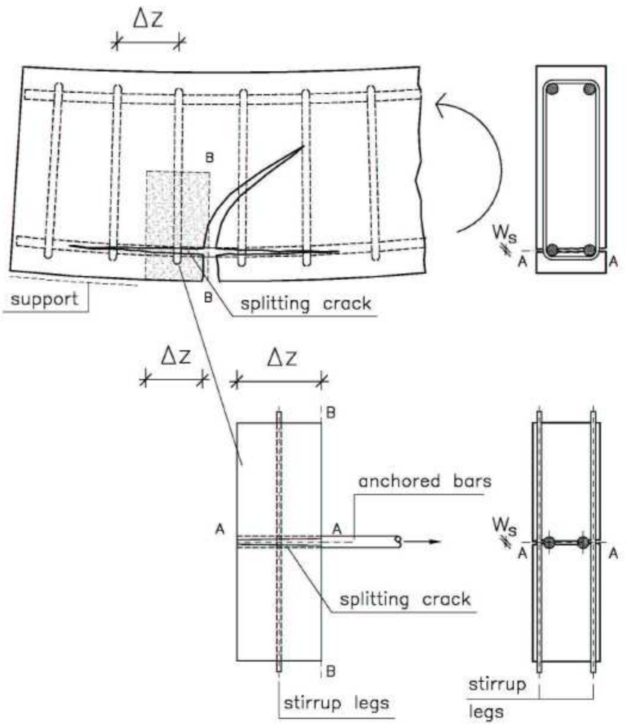

Figura 1: Static scheme in the real case of a beam and in the specimen of the experimental test.

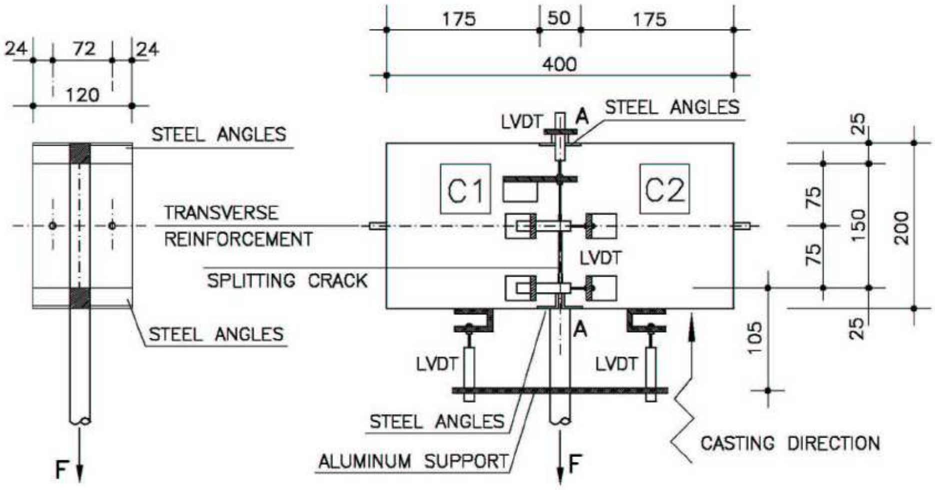

Figura 2: Geometric dimensions of the specimens in the experimental test with controlled confining action.

Similarly to the beam tests performed according to the CNR-UNI 10020 (1971), the length of the anchored zone was 10 times the diameter, namely 150 mm and 200 mm for ϕ16 e ϕ20 rebars, respectively.

The transverse confining reinforcement was disposed perpendicular to the plane AA, where the main splitting crack formed, so that the stirrups had the maximum stress due to the radial thrust of the rebars ribs (Figure 2). The length of the transverse reinforcement is equal to that of the concrete prism; in this way the reinforcement can be considered unlimited with respect to the slippage next to the crack (Figure 2). The ribs of the stirrups were oriented in order not to create thrusts towards the external surface of the specimen.

The specimen width was chosen in order to have a concrete cover equal to two times the diameter of the anchored rebar diameter, which is representative of the real cases.

When designing anchorages of ribbed rebars, reference should be made to two particularly significant parameters (Giuriani et al., 1991):

- the stirrup index of confinement

$$\Omega = \frac{A_{st}}{A_p} = \frac{n_{st}\, A_{st}}{n_p \phi_p \Delta z}$$

where n_p and $\emptyset_p$ are the number and the diameter of the stirrups; n_{st} and A_{st} are the number and the area of the stirrups in the influence zone Δz (Figure 3).

This index is particularly suitable for representing the confining action of the transverse reinforcement, because it represents the relationship between the total transverse reinforcement and reinforcement anchored in the area of influence of one stirrup. The area of the anchored rebar was evaluated based on a longitudinal section passing through its center in order to be more representative of the radial thrust exerted by the ribs (Giuriani et al., 1991).

- the concrete index of confinement

$$\mathrm{B} = \frac{A_{st}}{A_p} = \frac{(b - n_p \phi_p)}{n_p \phi_p}$$

where b is the width of the beam (Figure 3). This index is particularly suitable for representing the confining action of the concrete as it represents the ratio between the area of the concrete in the plane of the main splitting crack and the area of the longitudinal reinforcement.

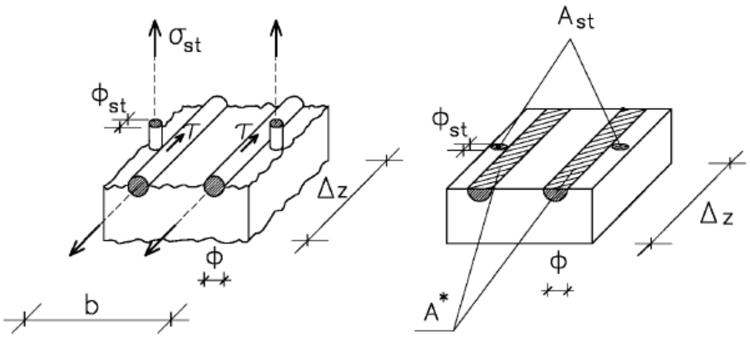

Figura 3: Geometrical parameters for the local behavior of bond around a stirrup.

Table 1 shows the diameter of the main rebar ($\emptyset_p$), the diameter of transverse reinforcement ($\emptyset_{st}$), the width (b) and the stirrup index of confinement (Ω) and the concrete (B) of all the specimens. One should notice that, for each type of sample, four specimens were tested and two of them were greased. Moreover, it can be noticed that the size of the specimens was chosen in order to have the same concrete index of confinement (B = 4) and so that the specimens with Ø16 rebar and specimens with Ø20 rebar and Ø8 stirrups had the same stirrup index of confinement (Ω). The second type of specimens with Ø20 rebars had a greater value of Ω and therefore a greater transverse confinement.

Tabella 1: Geometrical dimension of the specimens.

Specimen	ϕ_p[mm]	ϕ_{st}[mm]	b[mm]	Ω	B	Surface
C10P2S0A	20	10	100	0.0395	4	Greasy
C10P2S0B	20	10	100	0.0395	4	Greasy
C10P2S0C	20	10	100	0.0395	4	Clean
C10P2S0D	20	10	100	0.0395	4	Clean
C10P2S8A	20	8	100	0.0250	4	Greasy
C10P2S8B	20	8	100	0.0250	4	Greasy
C10P2S8C	20	8	100	0.0250	4	Clean
C10P2S8D	20	8	100	0.0250	4	Clean
C16P2S6A	16	6	80	0.0233	4	Greasy
C16P2S6A	16	6	80	0.0233	4	Greasy
C16P2S6A	16	6	80	0.0233	4	Clean
C16P2S6A	16	6	80	0.0233	4	Clean

The casting was done in the same direction of the main reinforcement and in the direction opposite to that of the pull-out force (F), in order to ensure a better behavior of concrete during the test (Rehm, 1961; Figure 2).

3. INSTRUMENTATION

The instrumentation adopted allowed to measure the pull-out force applied to the rebar, the loaded and unloaded end slips of the rebar as well as the splitting crack opening (measured close to both the loaded side and the transverse reinforcement).

To measure the displacement (d) of each anchored bar, two LVDTs (Linear Variable Displacement Transducer) were employed in order to take into account of possible rebar rotation (Figure 2).

The aluminum angles of LVDTs were settled on the specimen side in contact with the steel contrast plate. The loaded end slip (δ_L) was determined by subtracting from the measured displacement (δ) the elastic deformation of rebar in the area between the point of application of the LVDTs and the beginning of the anchored zone, equal to about 105 mm (Figure 2).

In order to measure the unloaded end displacement, a LVDT located near the free end of the rebar was employed (Figure 2).

The splitting crack opening was measured by means of LVDTs; the measure of the LVDT is equal to the crack opening because the elastic deformation of concrete in this zone is negligible (Figure 2).

The pull-out force applied at each anchored rebar was measured by means of 500 kN load cell of the Instron 1274 hydraulic servo-controlled testing machine.

All analog signals from the strain gauges and the LVDTs were converted to digital signals by means of control unit HBM UPM100, and then stored in a personal computer with a frequency of approximately 0.2 Hz.

The splitting crack formation and propagation were highlighted by applying a thin layer of white plaster, on the specimen surface, at the crack region. The position of the splitting crack tip during its propagation along the specimen was detected by means of a magnifying lens (6x).

4. TEST SET UP

However, the pull-out tests are generally influenced by the confinement action due to the friction, between the head surface of the specimens and the contrast plates, that is only related to the experimental test and is not present in anchored rebar of a real structure, contrary to the confining action due to transverse reinforcement and concrete.

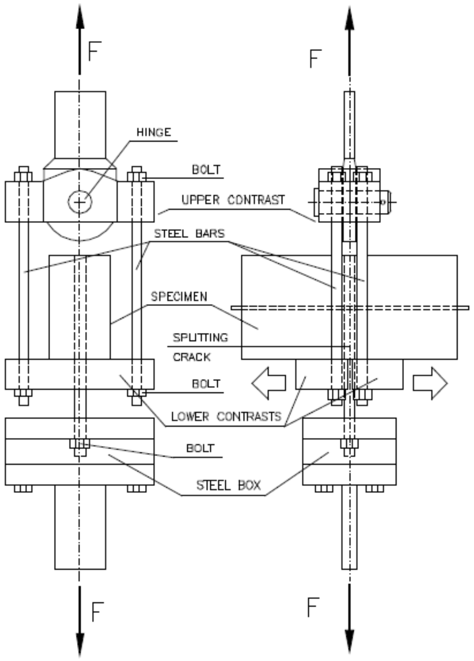

Figura 4: Test set-up.

In order to avoid disturb due to friction between the surface of the head of the specimens and the contrast plates, which is not present in a real structure, the tests were performed using the test set-up designed by Plizzari, Deldossi and Massimo (1998). The test set-up allowed the free splitting crack opening, through a counteracting system, which consisted of two plates along the plane of the crack itself (Figure 5). These steel plates, 60 mm thick, were connected to the counteracting element by means of bolted steel bars which, behaving like connecting rods, do not exert any confinement action on the specimen. The possibility of relative displacement between the two concrete blocks C1 and C2 means that bond depends on the confinement due to transverse reinforcement and concrete cover, as occurs in the real condition of a rebar anchored in a concrete beam. The splitting crack arises due the radial force exerted by the ribs of the rebar and initially starts between the two concrete blocks C1 and C2, which, as stated above, can move apart by inducing tensile stresses in transverse reinforcement (Figure 5).

The test bench is a counteracting set-up, which has to be put into the Instron testing machine 1274 and directly connected to the upper clamp of the Instron with respect to which it can rotate by means of an appropriate joint (Figure 4).

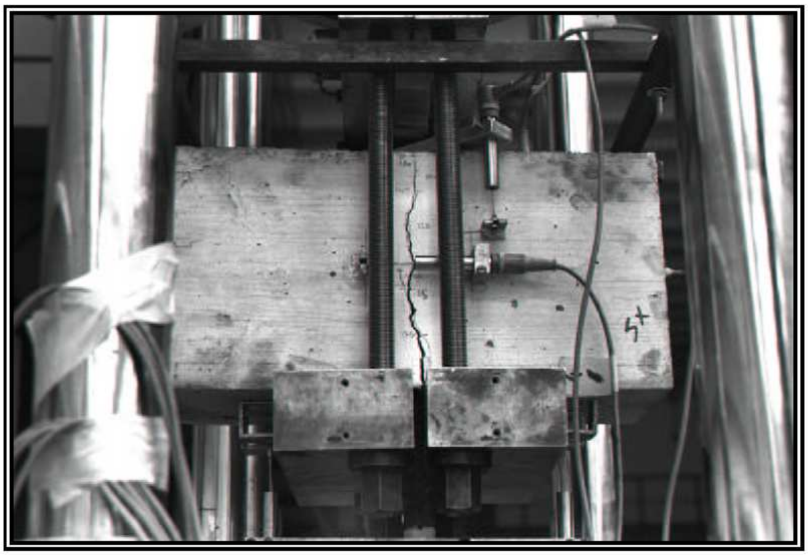

Figura 5: Picture of a specimen at the end of the test with evidenced the splitting crack.

5. MATERIALS

5.1. Concrete

For the tests was used a medium strength concrete having the following composition:

- Portland cement Type II 32.5R A/L-R: 325 kg/m^3;
- water: 175 l/m^3 (water/cement ratio = 0.54);
- rounded shape aggregate with siliceous composition: 1853 kg/m^3;
- superplasticizer 3.3 l/m^3.

Natural river aggregates with siliceous composition and rounded shape were employed and their distribution is reported in Table 2 (notice some overlap in diameters characterizing the different sizes of the aggregates used). The particle size distribution of the aggregates is shown in Table 1: for each size, the nominal diameter, the percentage passing through a sieve and the relative weight to the unit volume of concrete is reported.

All the samples were cast with the same concrete batch.

The aggregate distribution was designed by taking into account the cement dosage and the water/cement ratio, chosen to obtain the target workability and resistance, in accordance to the Bolomey curve, described by the following equation:

$$p\% = \left[A - C\% + (100 - A) \cdot \sqrt{\frac{d_{nom}}{D_{max}}} \right] \cdot \frac{100}{100 - C\%}$$

where:

p% is the percentage passing at the sieve with the equivalent diameter (d_{nom});

D_{max} (15 mm) is the maximum aggregate diameter;

A is a parameter chosen equal to 10;

C% is the cement percentage relative to the weight of both the aggregates and the cement itself.

The batches were cast in wooden formworks pretreated with release agents; the concrete was vibrated in three successive stages corresponding to three filling levels of the formwork.

Six cylinders (ϕ = 80 mm, l = 300 mm) and eight cubes (L = 150 mm) were also cast in order to evaluate the mechanical properties of concrete.

The workability of concrete was measured through the slump test, which provided a value of about 150 mm.

The specimens were removed from their formworks after 72 hours. Test samples, cubes and cylinders were placed into a fog room with constant temperature (T) and relative humidity (RH) (T=±20°C; RH>90%) up to two weeks of the experimental tests; thereafter, specimens continued their maturation in the laboratory, with relative humidity of approximately 70%.

The elastic modulus (E_{mean}), the compressive strength (f_c) and the tensile strength (f_{ct}) were obtained from tests on cylinders at 28 days, whereas cubes were used for determining the compressive strength (on two cubes) at the day of testing. All the results are reported in in Table 3.

Tabella 2: Grain size distribution of the aggregates.

Aggregate class (diameter range)	**Nominal diameter d_{nom}**	**Cumulative percentage passing**	**Weight**
[mm]	**[mm]**	**[%]**	**[kg/m^3]**
0-0.35	0.35	9.74	176.90
0.35-0.45	0.45	11.92	39.60
0.40-0.6	0.6	14.77	51.80
0.6-1.5	1.5	27.15	224.80
1.5-2.5	2.5	36.96	178.00
2.5-3.5	4.00	48.48	209.20
4.0-6.0	6.00	60.84	224.50
7.0-12.0	10.00	80.45	356.00
10.0-15.0	15.00	100.00	355.00

Tabella 3: Mechanical properties of concrete.

$E_{c,28}$	$f_{c,28}$	$f_{ct,28}$	$f_{c,cube}$
[MPa]	**[MPa]**	**[MPa]**	**[MPa]**
30650	28.3	2.25	31.9

5.2. Steel

Tempcore © FeB 44 k steel (B450C) was used for ribbed rebars. In Table 4 are reported the values of the geometrical and mechanical properties of the rebars employed.

Tabella 4: Mechanical properties of steel of anchored rebars.

Φ	**Type of steel**	**length**	**Yield**	**Rupture**	**A_5**	**A_{gt}**	**E**
[mm]	**[-]**	**[mm]**	**[MPa]**	**[MPa]**	**[%]**	**[%]**	**[GPa]**
16	B450C	500	550.1	653.3	25	13.1	198.9
20	B450C	600	535.2	642.6	23.75	12.8	199.1

Some rebars, before casting, have been completely immersed in oil and let drain so that the surfaces remain greased without oil in excess.

6. TEST PROCEDURE

The rebar is pulled-out from the sample of concrete by controlling the displacement of the loaded end of the rebar through the servo-control of the machine. The displacement rate imposed was equal to 0.002 mm/min up to the peak load, beyond which it was increased gradually. The actual rate of the slip imposed was well below the displacement imposed by the testing machine because of the gaps in the bolted joints of the bench and its elastic deformation. The average value of the rate of the loaded rebar slip displacement was about 0.0005 mm/min up to the peak load and is increased to 0.025 mm/min in the final phase of the test.

The quasi-static tests were carried out up to a maximum slip of 10 mm, equal to about the distance between the rebar ribs.

7. EXPERIMENTAL RESULTS

Figures 6-8 show the experimental results, expressed in terms of bond stress vs. the loaded end displacement. The bond stress was assumed uniformly distributed along the rebar and then was calculated as:

$$\tau = \frac{F}{\pi \phi \ell}$$

where:

F is the pull-out force of the loaded rebar;

ϕ is the rebar diameter;

ℓ is the length of the anchored zone (equals to about ten times the rebar diameter).

It can be noticed that, for all three types of test specimens, there were no significant differences between the bond behavior of the clean and greased rebars. Such behavior can be explained by considering that the rebar bond is mainly due to the mechanical interaction between the rebar ribs and the surrounding concrete. The layer of oil on the rebar surface reduces (or eliminates) the chemical bond between rebar and concrete which marginally influences the behavior of the rebar.

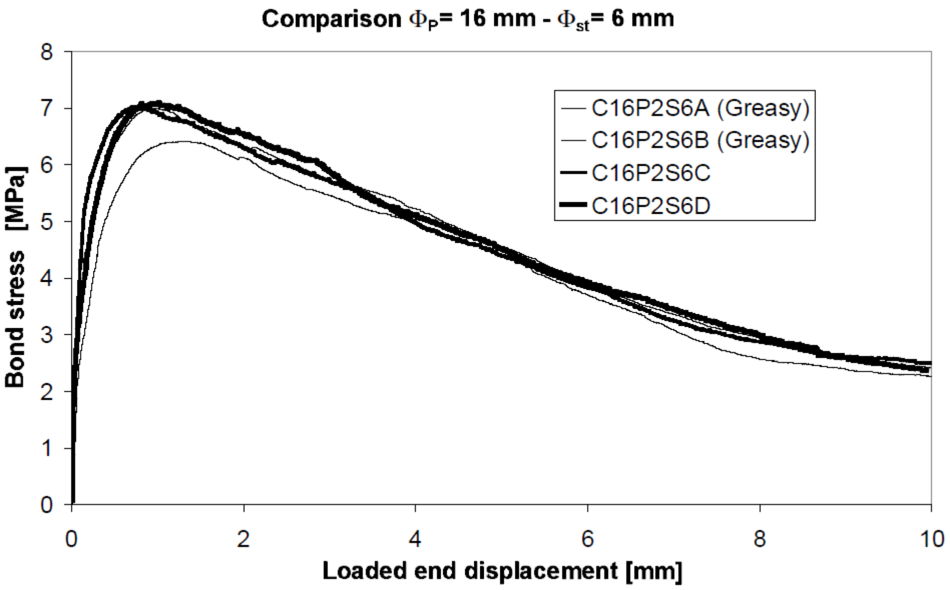

Figura 6: Loaded end rebar displacement vs. bond stress (specimens with ϕ16 rebar and ϕ6 transverse reinforcement).

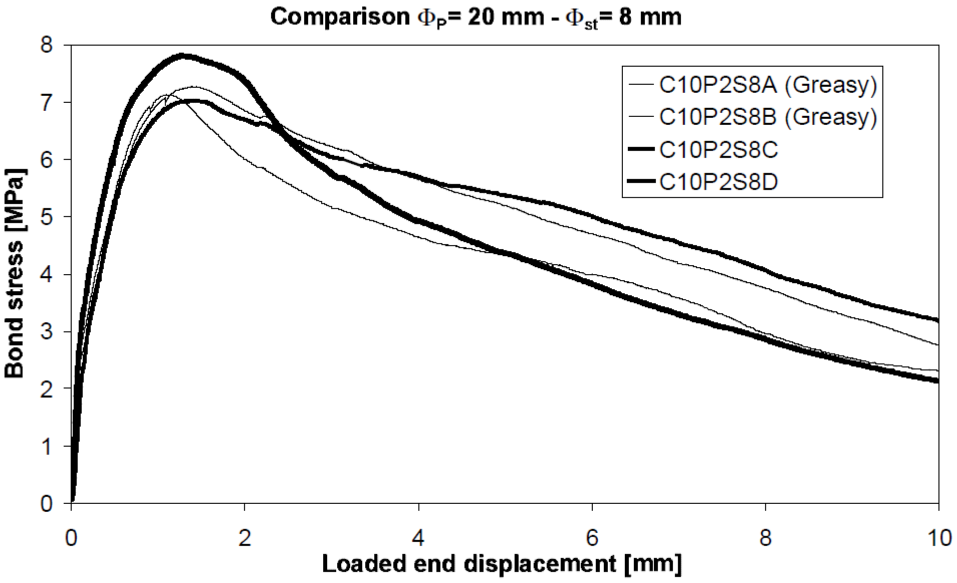

Figura 7: Loaded end rebar displacement vs. bond stress (specimens with ϕ 20 rebar and ϕ 8 transverse reinforcement).

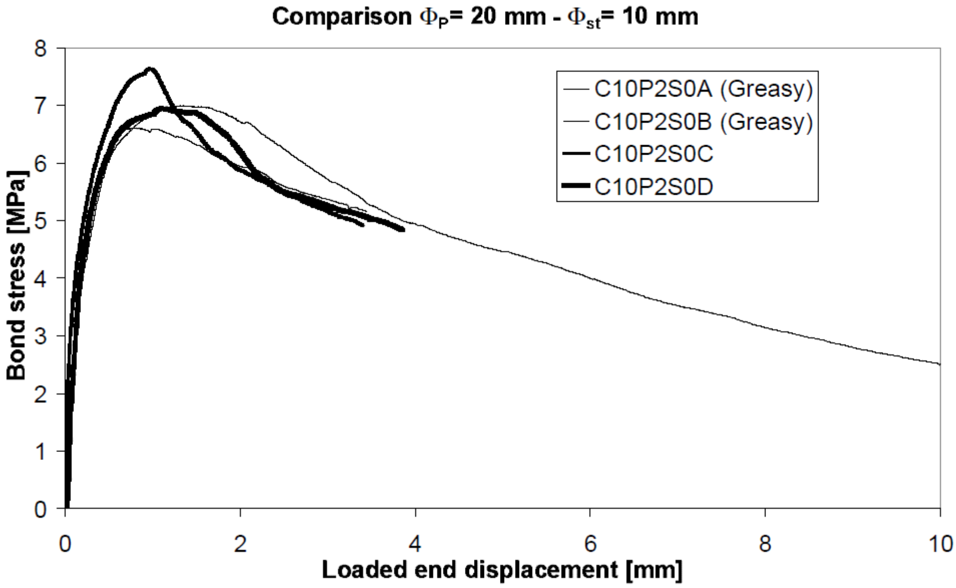

Figura 8: Loaded end rebar displacement vs. bond stress (specimens with ϕ20 rebar and ϕ10 transverse reinforcement).

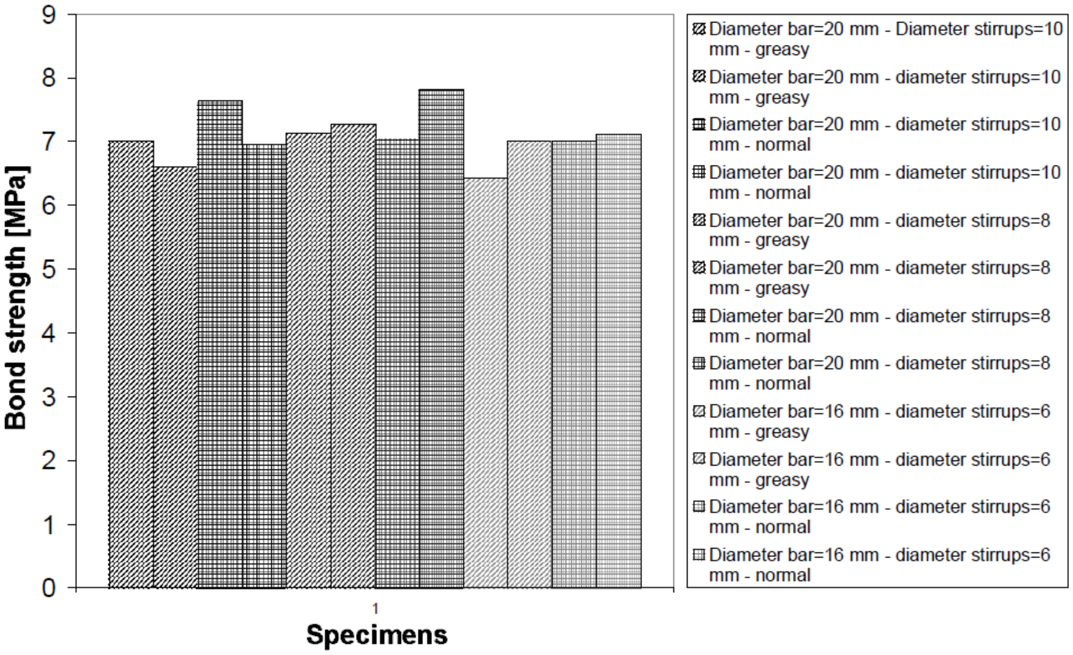

Figura 9: Bond strength for all the specimens tested.

Figure 9 summarizes the bond strength measured by all the tested specimens. It should be notice that the difference between the greased and clean rebars is generally very small and is often less than the difference shown in the previous figures between couples of identical specimens.

The bond strength of all the tested specimens, representative of actual situations of anchored rebars, was always well above the serviceability and ultimate values provided by the Italian and European Standards (DM 9.1.1996 and Eurocode 2, respectively) for a concrete class C25/30, which is often adopted in practice.

8. REFERENCES

- CNR UNI 10020:1971, Prova di aderenza su barre di acciaio ad aderenza migliorata.
- Rilem/CEB/FIP recommendation (1979): Bond test for reinforcing steel - 1. Beam test (RC5) - 2.Pull-out test (RC6).
- M.LL.PP., Decreto Ministeriale 9.1.1996, “Norme tecniche per il calcolo, l’esecuzione ed il collaudo delle strutture in cemento armato, normale e precompresso e per le strutture metalliche”.
- ENV 1992-1-1: Eurocodice 2 “Design of concrete structures – Part 1-1: General rules and rules for buildings”, European Prestandard, Dicembre 1991.

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