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# Study of the steel-concrete bond strength to recycled aggregates

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**ABSTRACT:** This study is interested in the connection between steel and concrete with recycled gravel. The work is carried out in the civil engineering laboratory of the Ecole Nationale Supérieure des Travaux Publics ENSTP and then completed in the mechanical engineering laboratory of the Institut National Supérieur des Sciences et Techniques d'Abeché INSTA. Two types of concrete are formulated, one with 100% ordinary crushed gravel and the other with 100% recycled gravel. In terms of compressive strength, the present study with 100% recycled gravel varies from 19 to 32 MPa at 28 days for the different dosages. And the concrete with ordinary crushed gravel offers a strength ranging from 22 to 37 MPa. Regarding steel concrete bonding, several types of reinforced concrete specimens are manufactured by anchoring a steel bar in the concrete. These specimens are subjected to the test of extracting the steel bar from the concrete. The values of the bond stress at rupture are calculated according to the formulas given by the Euro code, the BAEL, and then calculated experimentally. These values vary according to the compressive strength of the concrete.

**KEYWORDS:** Recycled aggregate, reinforced concrete, mechanical behavior, adhesion.

## 1 INTRODUCTION

In order to house and develop its environment, man has always used non-durable natural materials such as clay, wood, straw, etc. Over the centuries, societies have gradually evolved and developed urban habitats and communication routes by turning to durable materials such as rocks (granite, limestone, sandstone, etc.). Nowadays and especially in the city of N'Djamena, damages often occur in the structures, which causes the demolition of the works and the deposits of waste are made everywhere. This is where the recycling of concrete waste originates to make gravel that is sold in the curbs of some streets of the city. What are these gravels used for? Do they meet the mechanical requirements for use in civil engineering structures? To answer these questions, the mechanical characterization of concrete made from recycled gravel is of paramount importance. This characterization is based on the bond between steel and concrete. In 2005, Dominguez [1] studied the steel-concrete bond by the pull-out test of a steel bar in concrete, Antoine Tixier [2] made the same study but by the push-in test of a steel bar in concrete.

## 2 MATERIALS AND METHOD

Recycling is generally done on concrete waste, more precisely in N'Djamena at the edges of certain streets. This activity, in its embryonic stage, consists of manually crushing hydraulic concrete, masonry and other waste such as tiles, paving stones, etc.

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*Fig. 1. Concrete waste*

### 2.1 MATERIALS

The work of this study was carried out at the Laboratoire du Bâtiment et des Travaux Publics of the Ecole Nationale Supérieure des Travaux Publics LBTP/ENSTP of N'Djamena in Chad. The tests concern the compression and extraction of a steel bar anchored in a concrete specimen and according to the standards which indicate the principle, the material and the operating mode.

### 2.2 METHOD

The present formulation is 100% recycled gravel. The cement used is locally manufactured called Ciment de l'Afrique (CIMAF) of class CPJ 35. Two types of sand come from the Chari River, one at the Chagoua site (SCC) and the other at the Klesoum site (SCK). Concrete specimens with a diameter of 16 cm and a height of 32 cm were made and then stored before being subjected to compression at 3, 7 and 28 days. Three different dosages were calculated. They are 300 Kg/m3, 350 Kg/m3 and 400 Kg/m3.

#### 2.2.1 COMPRESSION

The compression test is carried out according to standard NF EN 12390-4[1]. It consists in loading a specimen until rupture in a machine for compression test. The maximum load reached is recorded and the compressive strength calculated by the formula below.

$$fc = \frac{F}{A} \tag{1}$$

Where: F is the load at failure of the specimen and A is the cross-sectional area of the specimen.

[1] Norme NF EN 12390-4.

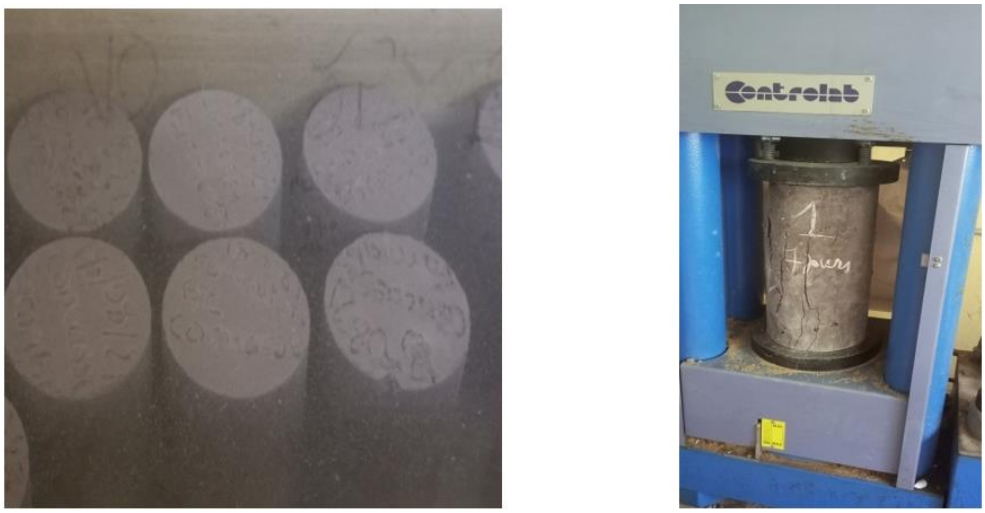


*Fig. 2. Preservation and crushing of specimens.*

### 2.2.2 ADHESION

The extraction of a steel bar called pull-out is carried out with the help of the concrete press consisting in applying a force on one of the ends of a steel bar anchored in a concrete specimen, the other end being free. The study of the bond consists in recording the bond strength at failure of the specimen and then observing the different shapes of the tested specimens after failure.

The bond stress is calculated:

According to euro code: fbd=2,25η_1 η_2 f_ctd (2)

According to BAEL[2]: τ_su=0,06ψ_s^2 f_tj (3)

Experimentally, the bond force is recorded and the bond stress is calculated by the formula:

τ_su=F/ (πØL) (4)

πØL is the lateral area of the steel bar.


*Fig. 3. Extraction of steel from a concrete block*

[2] Béton Armé aux Etats Limites BAEL

## 3 RESULTS AND DISCUSSION

### 3.1 COMPRESSIVE STRENGTH

The concrete compressive strength test was carried out on cylindrical specimens of 16 cm diameter and 32 cm height. Using a hydraulic concrete press, a compressive stress is applied monotonically to both circular faces until failure. The maximum force is recorded and using formula I.3, the compressive strength is calculated. The results are presented in tables and curves.

***Table 1. Value of the compressive strength according to the dosage and the quality of the sand***

| | | | Dosage (en Kg/m³) | | |
|---|---|---|---|---|---|
| | | | **300** | **350** | **400** |
| **Concrete with recycled gravel** | **SCC** | 3 | 4,63 | 5,97 | 6,13 |
| | | 7 | 7,88 | 11,9 | 16,13 |
| | | 28 | 20,12 | 19,3 | 32,0 |
| | **SCK** | 3 | 5,74 | 7,27 | 8,44 |
| | | 7 | 10,28 | 14,56 | 17,33 |
| | | 28 | 26,48 | 33,57 | 36,25 |
| **Concrete with ordinary crushed gravel** | **SCC** | 3 | 4,82 | 6,10 | 6,92 |
| | | 7 | 7,96 | 12,30 | 16,87 |
| | | 28 | 22,43 | 23,35 | 37,11 |
| | **SCK** | 3 | 7,28 | 7,55 | 7,70 |
| | | 7 | 15,15 | 15,20 | 17,28 |
| | | 28 | 32,70 | 37,6 | 40,80 |

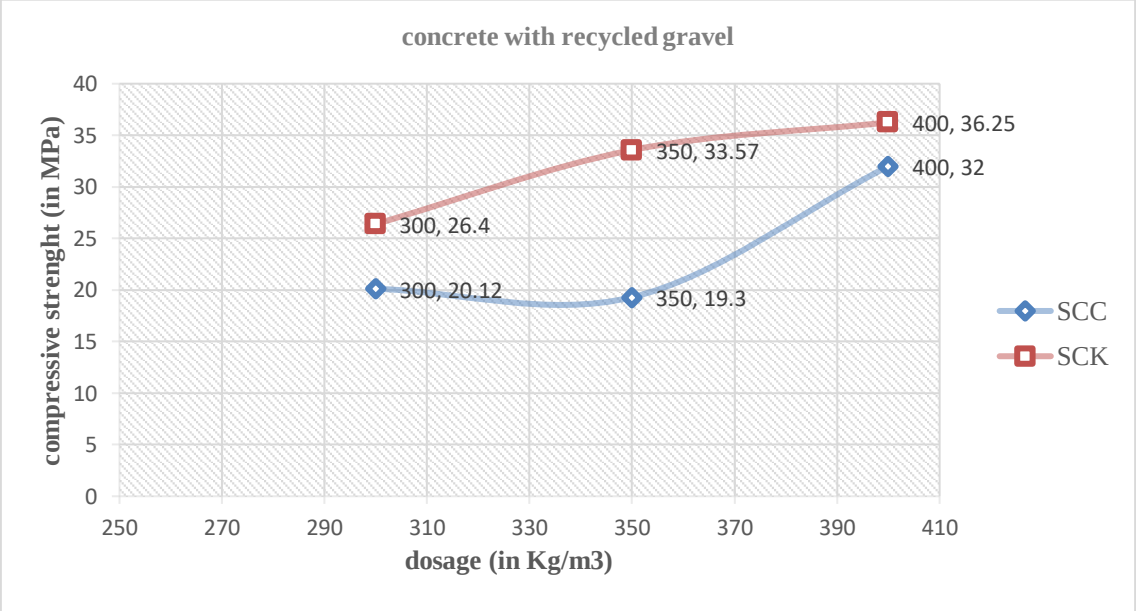


***Fig. 4. Compressive strength curve of concrete with recycled gravel as a function of dosage and sand***

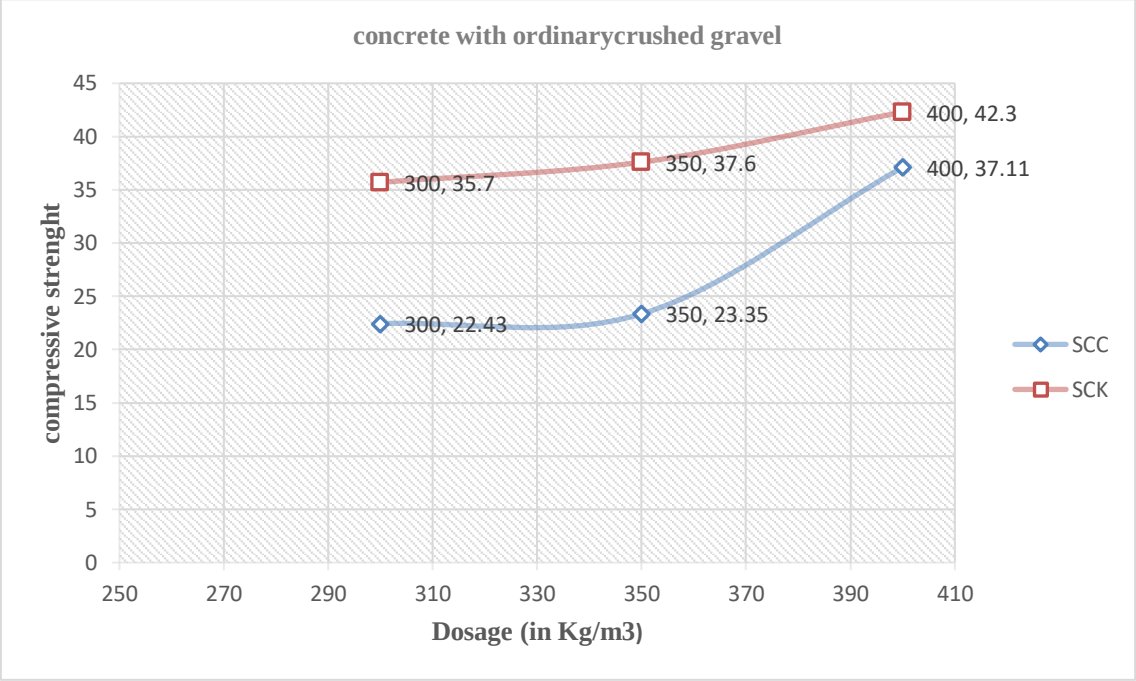


*Fig. 5. Compressive strength curves of concrete with ordinary crushed gravel as a function of dosage and sand*

For the concrete dosed at 350 Kg/m3, the compressive strength is compared with those of Guerzou Tourkia and Turcanu Vasile represented by the curves in the figure below.

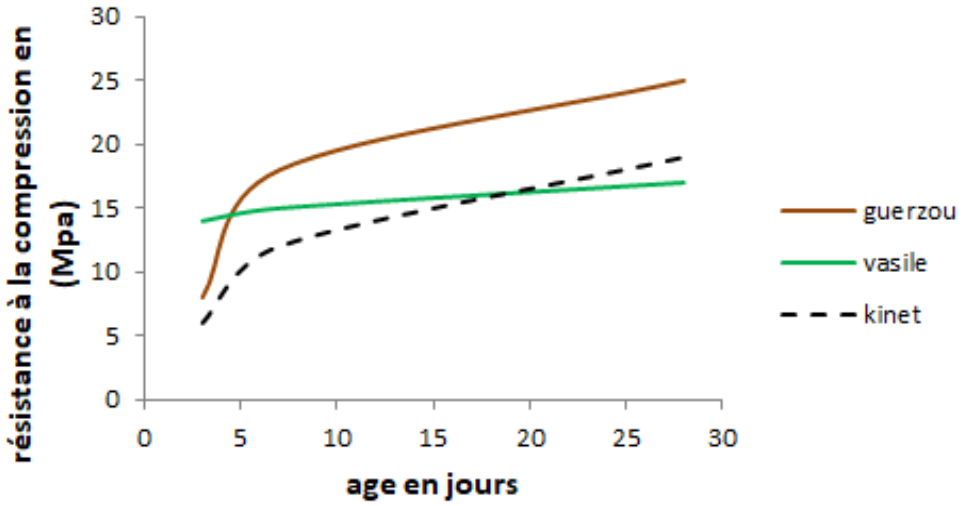


*Fig. 6. Compressive strength versus age curves*

Figure 6 shows that the compressive strength increases with the cement dosage. This justifies the logic of concrete with ordinary gravel, the strength increases with the cement dosage.

### 3.2 ADHESION

*Table 2. Value of the adhesion stress*

| | | Dosage (Kg/m3) | | |
|---|---|---|---|---|
| | | **300** | **350** | **400** |
| Theoretical Value (Mpa) | Eurocode Formula (2) | 2,25 | 2,25 | 3 |
| | BAEL Formula (3) | 0,244 | 0,237 | 0,340 |
| Experimental Value (Mpa) | Laboratory, Formula (4) | 1,20 | 1,00 | 1,85 |

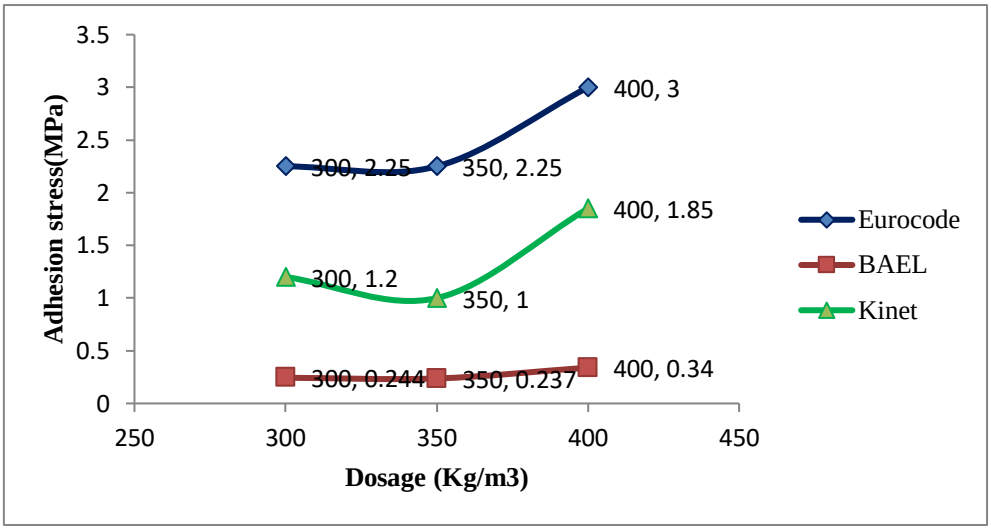


*Fig. 7. Comparison of adhesion stress curves as a function of dosage*

Figure 7 shows that the adhesion with recycled gravel is not negligible because its curve lies between the two theoretical values.

With the tensile machine, Figure 3 (b), the bond failure force is 25.670 KN for steel bars of 12-millimeter diameter and 200 mm interface length and 38.820 KN for bars of 14-millimeter diameter and same interface length. Using the formula (4) above, the bond stress is of the order of 4MPa. Ordinary crushed gravel, on the other hand, offers breaking forces ranging from 46 to 49 KN for Φ12 bars or about 6MPa stress and forces of 88 to 89 KN for Φ14 bars, or about 10 MPa stress. For Eligehausen and co-workers, the peak strength of the bond in the presence of longitudinal cracks varies from 2 to 7MPa. Antoine Tixier, using the push-in test, obtains forces ranging from 80 to 100 KN depending on the different formulations. Considering the theoretical (euro code) and experimental values obtained in the laboratory (1 to 3MPa), they belong to those of Eligehausen and collaborators and are almost the same as those of Tixier. In spite of these comparisons, these values show that concrete with recycled gravel has a lower bond strength than concrete with ordinary gravel.

## 4 CONCLUSION

The identification of the studied recycled aggregate shows that some of its characteristics are poor and others are acceptable. However, these deficiencies can be overcome if corrections are made. From the concrete point of view, the deficiencies can come from other components such as cement, sand or even the calculation of the dosages. For their use, recycled gravels can be oriented in road works in curbs, sidewalks and pavers or the manufacture of canals.

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