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INVESTIGATION OF STRESS - STRAIN BEHAVIOUR OF RECYCLED AGGREGATE CONCRETE UNDER CYCLIC LOADS

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Abstract

The recent awareness about recycling also involves the resources used in civil engineering. The use of Recycled Aggregate Concrete (RAC) has several advantages in terms of conservation of natural resources and of reduction of pollution. Although the interest on the use of structural concrete with recycled aggregates is increasing, extensive studies on the mechanical behaviour of such materials that can allow their use in alternative to standard concrete are still lacking. As a consequence most of the structural codes do not provide any information on the mechanical characteristics of RAC while other codes just provide very basic information. This paper presents the results of an experimental investigation about the mechanical behaviour of recycled aggregate concrete under uniaxial and cyclical compressive loads. Both monotonic complete stress–strain curves and cyclic behaviour under high-level compressive loads were analysed. Stress – strain behaviour of RAC is particularly significant for a subsequent analytical investigation of the mechanical behaviour of the material. Indeed, the envelope diagram provides the modulus of elasticity, the elastic deformation, the proportional limit, the peak resistance and the total elongation, useful to understand the mechanical capabilities of the material and to plan further experimental tests. The cyclic tests were made with repeated loads with values varying between 25% and 75% and between 25% and 80% of the peak load. The aim of the tests was to evaluate the decay of the mechanical properties over time due to fatigue-induced damage. Three different percentages of recycled coarse aggregate, namely 0%, 50% and 100%, have been investigated in each test. The objective of the experimentation is to provide more information on the mechanical properties of concrete with recycled aggregates in order to better model their behaviour and to enhance their use in civil engineering.

Key words: compressive test, cyclic loads test, recycled aggregate concrete, stress-strain curve

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1. Introduction

Environmental sustainability is an important issue concerning the protection of the natural world, with particular accent on preserving the environment from the dangerous impact that human activities can have on it (Nicuţă et al., 2013). In this contest, the research of alternative solutions to reduce demolition and construction waste is becoming an increasingly popular issue (Muscalu et al., 2013; Simion et al., 2013). The reuse of recycled aggregates (RA) or recycled concrete aggregates (RCA) has several advantages: the conservation of the natural sources, the reduction of the environmental costs of exploitation and transportation of virgin materials and the reduction of landfills where the C&D waste material is disposed.

Nevertheless, the use of recycled material meets many barriers and obstacles due to lack of confidence with this material and to the lack of laws and standards for its use as aggregate for structural concrete. However in the recent years the interest to perform research on these materials grew up. The most common technologies for concrete recycling utilize RCA as road sub-base material and in non-structural concrete. The reuse of hardened concrete as

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new aggregate could also allows structural uses. The old concrete can be crushed and reused as a partial replacement for natural aggregate in new concrete constructions. The hardened concrete can be sourced either from the demolition of concrete structures at the end of their life or from leftover or surplus fresh concrete. Generally, performances of recycled aggregate concrete are comparable with those of concrete made with natural aggregates. However, before its extensive use in civil engineering, it is essential to understand the mechanical behaviour of recycled aggregate concrete. This paper is aimed at improving the knowledge of the mechanical properties of concrete realized with recycled concrete aggregates. In particular complete stress – strain curves and low-level cyclic tests has been performed on specimens with different RCA contents in order to evaluate the decay of the mechanical properties over time due to fatigue-induced damage.

The paper is organized as follows: Section 2 gives a background about research on the recycled aggregate concrete, with focus on fatigue behaviour; Section 3 presents the materials' properties and the experimental methodology; Section 4 presents the experimental results of displacement-controlled tests and cyclic tests; Section 5 concludes the paper.

2. Background

The use of recycled aggregates concrete has several advantages in terms of conservation of natural resources and reduction of pollution. Although the interest on the use of this new material is increasing, studies on several mechanical properties that could facilitate its use in alternative to standard concrete, such those on its fatigue strength, are still lacking.

Among all recycled aggregates, the most suitable ones for the production of new structural concrete are the recycled aggregates coming from concrete crushing (Recycled Concrete Aggregates - RCA). Nevertheless, even if it is generally agreed that there is a loss in the physical and mechanical properties of RAC if compared to natural aggregate concrete (Breccolotti and Materazzi, 2010, 2013), their fatigue behaviour has not been extensively analysed.

Fatigue studies on Natural Aggregate Concretes (NAC) have been undertaken since the beginning of the twentieth century (Van Ornum, 1907) reaching a consolidated state of knowledge. As far as NAC are concerned, Holmen (1979) and other authors observed the same behavioural pattern with regards to the strain increase during the fatigue life of a specimen subject to constant stress levels. This pattern can be described as follows. In a first stage a quasi-logarithmic increase in the maximum and minimum strain is achieved, with the increase rate of the maximum strain being slightly higher than that of the minimum. This stage corresponds to the initial formation of micro-cracks. During the second stage, associated with the growth and stabilization of the formed cracks, these strains grow following a linear trend until the third stage is reached. In this latter the interconnections of cracks cause the collapse of the concrete under fatigue loading. The increase in deformation, unlike the previous stages, is exponential. In the research of Petryna et al. (2002) a constitutive model for concrete subjected to cyclic loadings in both compression and tension is presented. This model was intended to provide improvements on modelling the cyclic behaviour of concrete structures in the context of computational programs based on a smeared crack approach. Particular emphasis has been paid to the description of the strength and stiffness degradation produced by the load cycling both in tension and in compression, the shape of unloading and reloading curves and the transition between opening and closing of cracks.

As far as lightweight aggregate concretes are concerned, the first studies about their fatigue strength, in particular on mix-design with different typologies of aggregate, were carried out during the sixties of the last century by Gray et al. (1961). The Authors performed fatigue tests on two different lightweight aggregate concretes, one with a high design strength and the other with low design strength. Specimens of approximately the same age were tested at different stress levels ranging from 40% to 80% of the ultimate static compressive strength of the respective mix-designs. Within the limits of the investigation, the fatigue behaviour of high strength lightweight concrete was similar to that of low strength lightweight concrete.

Only limited studies on the fatigue strength of RAC have been performed up to now and the results of experimental tests are not always in good agreement.

Xiao et al. (2013) carried out a research on the fatigue behaviour of RAC under uniaxial compression, in particular for the typology with 100% of recycled coarse aggregate. The main factors such as the residual strain variation, the fatigue strain variation and the fatigue modulus of RAC, were evaluated to find the relation between strain response and fatigue damage behaviour in RAC. The analyses didn't show significant differences between the fatigue compressive behaviour of RAC and NAC. Nevertheless, they observed by experimental tests two opposite trends in RAC's fatigue strength under uniaxial compression and bending cyclic loading: the fatigue life of RAC for the same stress level is higher than that of NAC under cyclic compression loading while the contrary is true under bending loading.

Yan et al. (2011) analysed the fatigue behaviour of RAC specimens subjected to axial and eccentric compression finding differences respect to non-recycled concrete. In fact, the Authors showed that, for the same water/cement ratio, the use of recycled aggregate in concrete implies a reduction of the fatigue life. There reduction is enhanced with smaller water/cement ratios due to the lower strength capacity of the recycled aggregates.

Luo and Yao (2011) analyzed the deformation curves and the response to ultrasonic pulses of recycled plain concrete subjected to low frequency fatigue. Their findings confirmed the presence of a damage accumulation similar to that observed by Holmen (1979) with amplitude of the three stages equal to 10%, 80% and 10% of the fatigue life, respectively.

Similarly, Thomas et al. (2014) observed that the three stages represent approximately 15%, 70% and 15% of the total life time respectively. The Authors also noticed that, for the same water/cement ratio, the use of recycled aggregate in concrete implies a reduction of the fatigue life in compression. This reduction is more evident for low water/cement ratios and the Authors suggest that such behavior is caused by the lower strength of the recycled aggregate in comparison to the natural ones.

Low cycle fatigue strength of RAC has been investigated by Gordon (2011) who carried out tests with three different w/c ratios and five natural aggregate replacements for a total of 224 concrete samples. The Author found that RAC concrete is virtually indistinguishable from a natural concrete up to a recycled coarse aggregates replacement of 25%. For higher values of replacement, RAC exhibits reduced resistance to degradation, increased stiffness degradation and a reduction in the energy dissipated during cycling.

3. Experimental program

To investigate the stress-strain behaviour of RAC under cyclic loads a two phases experimental program has been established. In the first phase tests have been carried out to evaluate the basic mechanical properties (compressive strength, elastic modulus and stress-strain envelope) of RAC. In the second phase tests with compressive and cycling load have been performed.

3.1. Materials

The recycled aggregates used in the experimental tests have been taken from 63 cubic specimens crushed in compression tests in a concrete testing laboratory (Fig. 1). Their compressive strength was between 30.1 and 32.1 MPa, with an average resistance of 32.5 MPa and a standard deviation σ of 0.716 MPa (Table 1). The concrete cubes were subjected to crushing to obtain recycled concrete aggregates (Fig. 2).

The aggregates used in the experimentation were investigated through the determination of the particle size distribution, the density in conditions of saturated surface dry (SSD), the absorption and the water content.

Through the particle size distribution, the percentage of different grain sizes contained within the aggregates has been achieved, according to Italian Standard Specificarions.

A representative dried sample of material was previously weighed and then sieved, following UNI EN 933-1 (UNI, 2012). The aggregates were analyzed by using a set of ASTM sieves with progressive smaller screen openings with dimension 40, 31, 5, 25, 20, 16, 12.5, 8, 4, 2, 1, 0.5, 0.25, 0.125 and 0.075 mm. Cumulative weight passing through each sieve is calculated as a percentage of the total sample weight. The results of the measurements and the particle size distributions of the natural aggregates are shown in Fig. 3. Differently from NA, it can be observed that RAC posses a continuous grain size distribution in the range 0.4 – 30 mm.

Fig. 1. Concrete specimens after compression test going to be recycled for new aggregates

Fig. 2. Recycled concrete aggregates after crushing

The estimation of the absorption and of the saturated surface dry (SSD) density of the aggregates have been carried out following the procedure of UNI EN 1097-6 (UNI, 2013) for fine materials, passing through the sieve with mesh size of 4 mm and for coarse aggregate, over 4 mm.

Table 1. Mechanical properties of concretes samples used for the recycled aggregates.

Concrete strength	*n. samples*	$R_{c,min}$ *[MPa]*	$R_{c,max}$ *[MPa]*	R_{cm} *[MPa]*	σ *[MPa]*	*COV*
C25/30	63	30.1	32.5	31.4	0.716	0.023

Table 2. Water absorption and SSD density of natural (sand and gravel) and recycled aggregates

Aggregate	*Water absorption [%]*	*Saturated Surface Dry particle density [kg/m³]*
Sand	1.70%	2650
Gravel 4/8 mm	1.70%	2657
Gravel 8/12 mm	1.70%	2662
RCA	5.24%	2340

Table 3. Water absorption and SSD density of fine and coarse recycled aggregates

Recycled aggregates	*Water absorption [%]*	*Saturated Surface Dry particle density [kg/m³]*	*Weight fraction*
Fine (< 4 mm)	7.70%	2222	25.6%
Coarse (> 4 mm)	4.40%	2381	74.4%

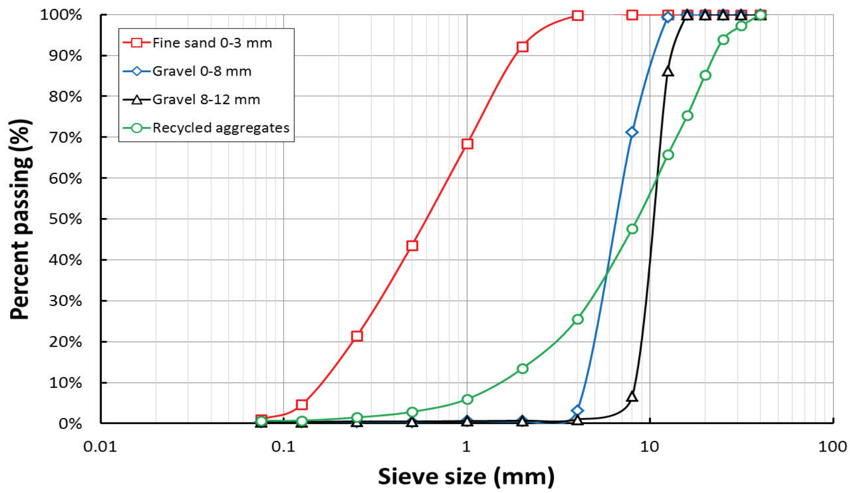

Fig. 3. Grading of natural (sand and gravels) and recycled aggregates

The representative values of the total recycled aggregates were obtained as a weighted average of the amounts of fine and coarse aggregate. For fine aggregate, water absorption and SSD density was calculated using Eqs. (1-2), where m_{ssd} is the saturated surface dry mass of 1 kg of aggregate, m_d is its dry mass, ρ_w is the water density, m_{p1} and m_{p2} are the pycnometer mass full of water and, respectively, with and ithout the original aggregate.

$$A = 100\frac{m_{ssd} - m_d}{m_d} \tag{1}$$

$$\rho_{ssd} = \rho_w \frac{m_{ssd}}{m_{ssd} - (m_{p1} - m_{p2})} \tag{2}$$

In the case of coarse aggregates water absorption and SSD density have been obtained as given by Eqs. (3-4), where V_{ssd} is volume of the saturated surface dry aggregate obtained by inserting the material into a graduated burette partly filled with a known quantity of water.

$$A = 100\frac{m_{ssd} - m_d}{m_d} \tag{3}$$

$$\rho_{ssd} = \rho_w \frac{m_{ssd}}{V_{ssd}} \tag{4}$$

Water absorptions and SSD densities are shown in Tables 2 and 3 for the natural and the recycled aggregates, respectively.

3.2. Specimens

The specimens for the investigation on the compressive strength and the complete stress-strain curve were cubes of 15 cm sides. For fatigue tests cylindrical samples with diameter of 10 cm and height of 20 cm has been investigated. A total of 48 cubic samples and 6 cylindrical samples were manufactured for those purposes. Cement type Portland 52.5 R was utilized. The water/cement ratio of the mixtures was 0.45.

To improve workability, a plasticizer was added in the amount of 0.8% by weight of cement. Table 4 summarizes the mix design of the different typologies of concrete realized for the experimentation. Table 4 lists the components by weight for a cubic meter of the realized concretes. The second column reports the mix design of the reference concrete. The third and the fourth columns describe the mix design of the recycled concretes where the natural coarse aggregate was substituted with respectively 50% and 100% of recycled coarse aggregate. For each mix-design, twin samples were realized. After the mixing and the cast, the samples of both natural and recycled concretes have been cured for 28 days in water at a controlled temperature of 20 °C.

Table 4. Mix design of recycled concretes

Component	*Content (kg/m³)*		
	0% RCA	*50% RCA*	*100% RCA*
Cement 52.5 R	400	400	400
Water	180	180	180
Plasticizer	3.2 L	3.2 L	3.2 L
Sand	996	978	1067
Gravel 4/8	373	302	-
Gravel 8/12	409	89	-
Recycled coarse aggregates	-	369	641
Water/cement ratio	0.45	0.45	0.45

a) **b)**

Fig. 4. a) Experimental setup; b) Sample during complete stress-strain test

Before carrying out the experimental tests the cylindrical samples were superficially leveled by diamond grinding to ensure the flatness of the surface of the bases.

3.3. Experimental set up and test procedure

Three different test typologies were performed. The first one was about the compressive strength evaluated by means of a force controlled test. The second one was about the assessment of the complete stress-strain curve by means of a displacement controlled test. It also allowed determining the highest peak strength of the different mix designs. The third test was a cyclic fatigue test between two specific loads. In particular two ranges of values have been used: from 25% to 75% of the peak strength and from 25% to 80% of the peak strength, in order to evaluate the fatigue behavior under low-cycle fatigue. Thus the maximum loads (75% and 80%) used in fatigue tests were relatively high and close to the peak compressive strength.

The lower limit of 25% has been chosen to represent the service load that concrete is expected to experience during its life in typical structures. According to the envelope theory (Sinha et al., 1964), the failure in the fatigue tests arises when the cyclic curve reaches the stress-strain curve. Since concrete is a rate dependent material, it has been necessary to study the rate of the applied load. At the end of the stress-strain test, the Young's module has been calculated in order to calibrate the loading rate of the fatigue test.

Both typologies of test were performed with a Controls Advantest machine with a maximum capacity force of 5000 kN, instrumented with three linear displacement transducers arranged at 120 degrees (Fig. 4). Specific software allowed the test performances under displacement control for the envelope curves and under load control for the cyclic tests. The stress-strain tests performed on cubic specimens have been carried out with a strain rate of 1 μm/s. For the stress-strain tests on cylindrical specimens, the displacement rate was set equal to 26.4 μm/s. The loading rate of the fatigue test has been estimated in order to ensure that the behaviour of the material was similar to that of the envelope test in terms of strength and stiffness, with an upper limit of 3.5 MPa/s.

4. Experimental results

4.1. Fresh concrete properties

During the realization of the mixes of normal and recycled concrete fresh density and workability has been investigated. Fresh concrete workability was estimate through slump and flow tests by Abrams cone. Slump test concerns the measure of the subsidence of a standard cone of fresh concrete, while the flow is the average of two diameters in orthogonal direction after spreading of the concrete.

The results show (Table 5) that the realized concretes belong to the class of consistency S5, super fluid. Table 5 shows also comparable values of the density of fresh concrete for the three types of concretes with a slight decrease of the density for higher content of RA.

Table 5. Results of the slump and flow tests

Concrete type	*Slump [cm]*	*Flow [cm]*	*Density [kg/m³]*
0% RCA	25.5	55.5	2368
50% RCA	26.2	67.7	2340
100% RCA	25.3	61.7	2278

4.2. Uniaxial compressive tests

After the proper curing period, cubic samples made of normal and recycled concrete were tested to investigate their compressive strength with a statistic approach. Resistance after 24 hours, 7 and 28 days has been evaluated. For each mix design two samples were tested after 24 hours and two samples after 7 days, while 9 specimens has been tested after 28 days of curing, in order to calculate the standard deviation and the coefficient of variation.

Before proceeding to the positioning of the specimens in the press, their mass has been evaluated, so to estimate the density of hardened concretes. The compressive tests on concrete cubes were performed following the UNI EN 12390-3 specifications (UNI, 2009). Tables 6 and 7 show the results of uniaxial compressive tests and the measurements of the average mass and the density during the curing time.

Since its early curing, the concrete with natural aggregate demonstrates higher compressive strength than those with recycled aggregates. Moreover, higher values of the coefficients of variation have been evidenced in recycled concretes in comparison with the normal one, highlighting a greater variability of their resistance.

4.3. Stress-strain curve tests

The stress-strain compressive behaviour with increasing strain of both normal and recycled aggregate concrete has been investigated by means of displacement-controlled tests described in the previous section. Figs. 5 and 6 show the complete stress-strain curves for the normal specimen and for the samples with 50% and 100% of recycled aggregates. In particular Fig. 5 is relative to cubic specimens, while Fig. 6 reports the results of the representative twin cylindrical specimens of that subjected to fatigue stress test.

The results appear consistent with the literature. Indeed, Xiao et al. (2005) found that RAC showed significant ductility decrease in the post peak region of the stress-strain curves. González-Fonteboa et al. (2010) observed opposite behaviour with a shift to the right in the stress–strain curves of the recycled concretes that becomes of considerable importance when the percentage of replacement is high. Such behavior is more visible in the results of the cylindrical samples. As observed by Dilger et al. (1984) this can probably be ascribed to the smaller confinement to which cylindrical samples are subjected that significantly reduces their ductility. The Authors also believe that the different speed of load application did not produce pronounced effects on the shape of the stress-strain curves.

Regard to the stress-strain tests on cylindrical samples, the peak compressive strength for the concrete with traditional aggregates is about 62 MPa, while the strength of concrete with 50% of recycled aggregates is 54 MPa and the compressive strength of the concrete with 100% of recycled aggregates is significantly lower and equal to 37 MPa. These results suggest that, given a certain concrete mix design, the replacement of standard quarry aggregates from recycled ones produces a lowering of concrete compressive strength. The Young's modulus, evaluated in correspondence of 0.4 times the peak strength according to the Italian standard NTC 2008, follows the same trend: concrete stiffness is higher for standard aggregate concretes, while it is lower for RAC.A summary of these data is reported in Table 8. As far as ductility is concerned, the lower the recycled aggregates content, the steeper the softening branch is. This observed behaviour allows authors to conclude that the use of recycled aggregate concrete produces an increase in ductility, partially due to the lower compressive strength.

Table 6. Results of compressive tests on samples of normal and recycled concrete after 24 hours and after 7 days of curing

Concrete type	*After 24 hours*			*After 7 days*		
	R_{cm} *[MPa]*	M_m *[kg]*	*Density [kg/m³]*	R_{cm} *[MPa]*	M_m *[kg]*	*Density [kg/m³]*
0% RCA	37.8	8.096	2399	55.5	8.176	2423
50% RCA	32.6	7.839	2323	53.1	7.959	2358
100% RCA	33.2	7.667	2272	46.1	7.676	2274

Table 7. Results of compressive tests on samples of normal and recycled concrete after 28 days of curing

Concrete type	R_{cm} *[MPa]*	M_m *[kg]*	*Density [kg/m³]*	*σ [MPa]*	*COV*
0% RCA	64.0	8.088	2396	2.42	0.038
50% RCA	61.0	7.911	2344	2.81	0.046
100% RCA	54.3	7.782	2306	2.31	0.043

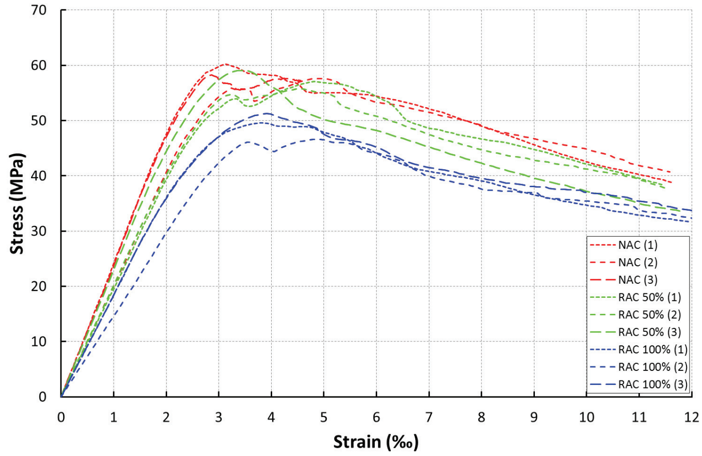

Fig. 5. Stress-strain curves for cubic specimens with different percentages of recycled aggregates content

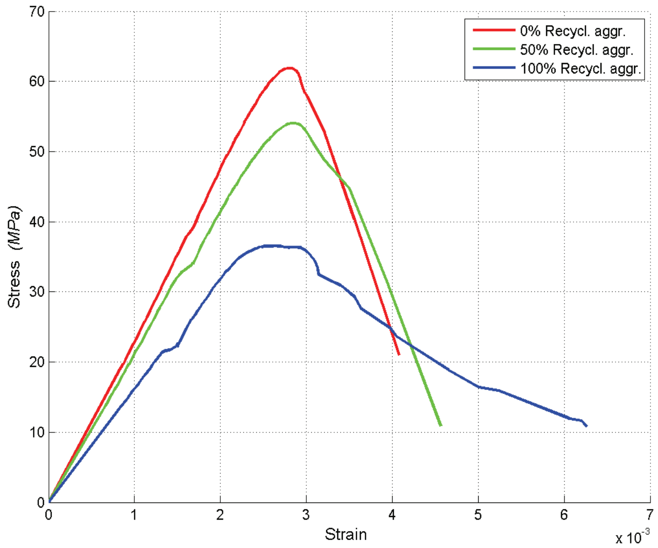

Fig. 6. Stress-strain curves for cylindrical specimens with different percentages of recycled aggregates content

Table 8. Mechanical properties of concretes with different content of recycled aggregates

Concrete type	*Compressive strength* *[MPa]*	*Elastic modulus* *[MPa]*
0% RCA	62	23053
50% RCA	54	21433
100% RCA	37	16301

4.4. Cyclic tests

In this section the results of fatigue tests on recycled aggregate concrete are presented. Authors studied how the variation of the recycled aggregates content influences the fatigue behaviour of concrete. These investigations have been performed using force-controlled tests having the lower bound equals to 25% of the concrete strength and the upper bound equals to 75% and 80% of concrete strength.

Table 9 summarizes the results of fatigue tests between 25% and 80% of concrete strength. In Figs. 7-9 the experimental stress-strain behaviour of, respectively, 0% (NAC), 50% and 100% recycled aggregate concrete is depicted side by side with the strain development with cycle progression.

Table 9. Fatigue behaviour of concretes with different content of recycled aggregates for loading cycles between 25% and 80% of peak compressive strength

Concrete type	*Strain at failure*	*Fatigue life* *(n° cycles)*	*Load frequency* *(cycles/min)*
NAC	$3.47 \cdot 10^{-3}$	400	3.20
50% RCA	$3.16 \cdot 10^{-3}$	236	2.99
100% RCA	$3.50 \cdot 10^{-3}$	271	3.35

The analysis of these results allows inferring the following facts. First of all fatigue induced failure occurs approximately when the fatigue stress-strain curve reaches the softening branch of the compressive envelope curve, as many authors have observed to happen for standard concrete. So no difference between this latter and RAC is observed in regards with this behaviour. As far as it concerns fatigue life no significant differences were observed by increasing recycled aggregates content from 50% to 100%. Strain development seems to resemble the trend described in literature according to which strain increases following a quasi-logarithmic rule during the first 15% of fatigue life, followed by a linear increase until about 85% of fatigue life, and finally failure is achieved with an exponentially increasing strain during the last 15% of specimen life.

In Table 10 results for fatigue tests between 25% and 75% of concrete strength are summarized. It should be noticed that for concrete with 50% of recycled aggregates content fatigue life was not observed during low cycles tests. In Figs. 10 and 11 the stress-strain curves for both 50% RAC and 100% RAC are depicted. By comparing these results with the previous ones it is clear how just a slightly lower upper bound on the applied load produces a significant increase in concrete fatigue life. Moreover, even if 50% RAC failure did not reached failure, the 100% sample illustrates how failure still occurs approximately when the stress strain path meets the softening branch of the envelope curve, regardless of the applied loading level. As a consequence, it can be concluded that a higher load level increases the plastic strain developed at each cycle but does not modify the failure mechanism.

Table 10. Fatigue behaviour of concretes with different content of recycled aggregates for loading cycles between 25% and 75% of peak compressive strength

Concrete type	***Strain at failure***	***Fatigue life*** *(n° cycles)*	***Load frequency*** *(cycles/min)*
NAC	n.a.	10117[a]	n.a.
50% RCA	> $2.59 \cdot 10^{-3}$	> 1838	3.14
100% RCA	$3.23 \cdot 10^{-3}$	1122	3.70

[a]*experimental data according to Kim and Kim (1996)*

5. Conclusions

The present work presents the first results of a study on constitutive laws and on fatigue behaviour of RAC. Compressive strength decreases with the RAC percentage increase in the mixtures. Indeed the peak resistances of concretes with 50% and 100% of recycled aggregates are respectively 13% and 40% lower than that of normal concrete.

Moreover, the tests show a decrease in the stiffness of RAC with respect to normal concrete, especially for the mix with higher percentages of recycled aggregates.

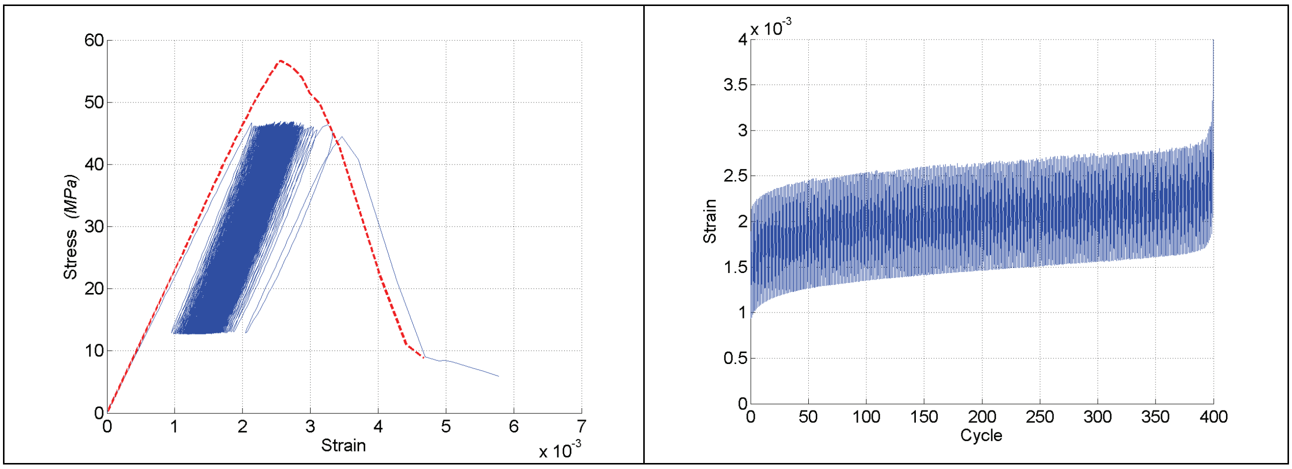

Fig. 7. On the left: fatigue stress strain behaviour of NAC loaded between 25% and 80% of peak strength. On the right: strain development with increasing cycles

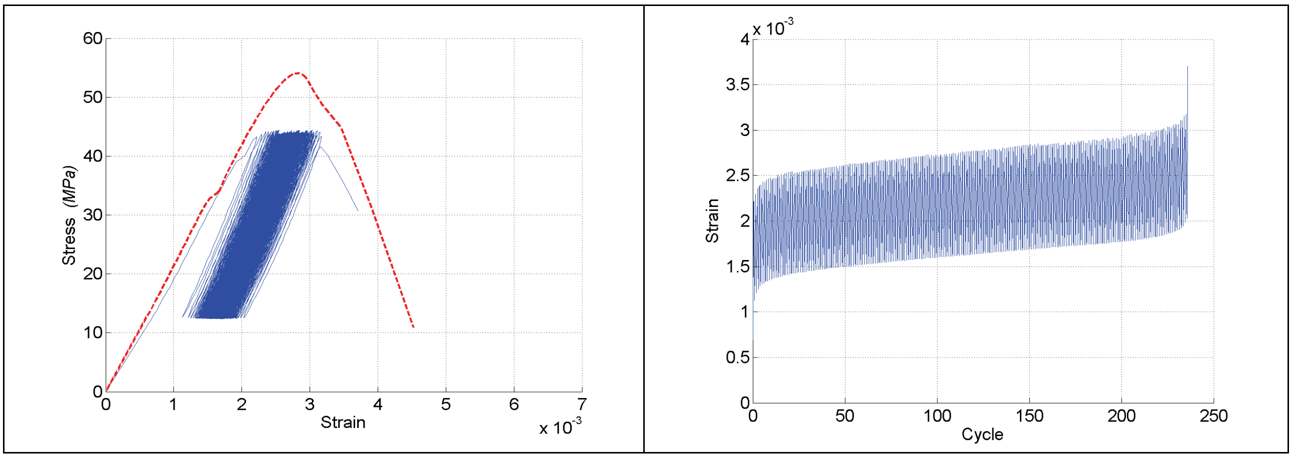

Fig. 8. On the left: fatigue stress strain behaviour of 50% RAC loaded between 25% and 80% of peak strength. On the right: strain development with increasing cycles

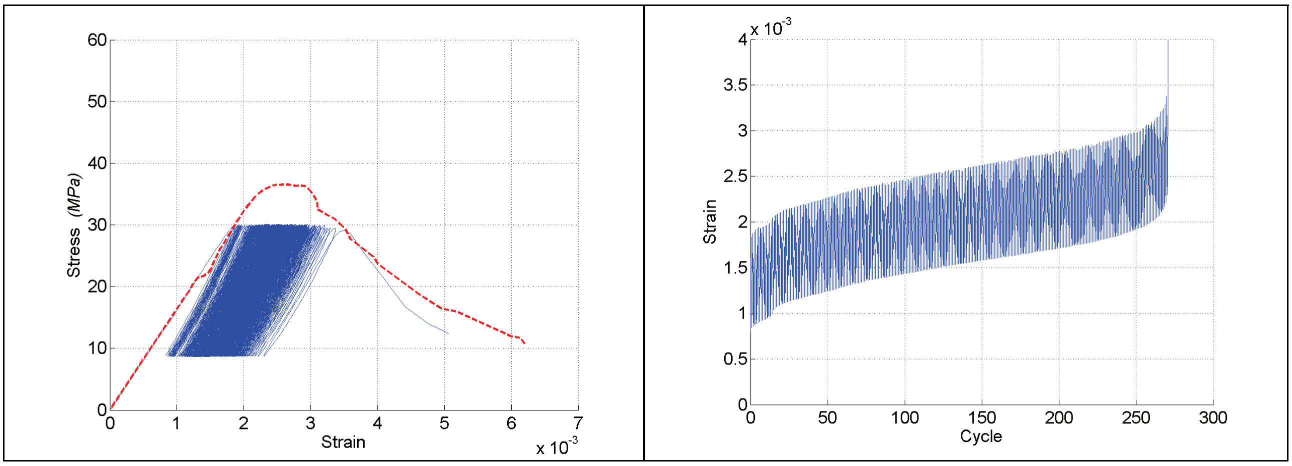

Fig. 9. On the left: fatigue stress strain behaviour of 100% RAC loaded between 25% and 80% of peak strength. On the right: strain development with increasing cycles

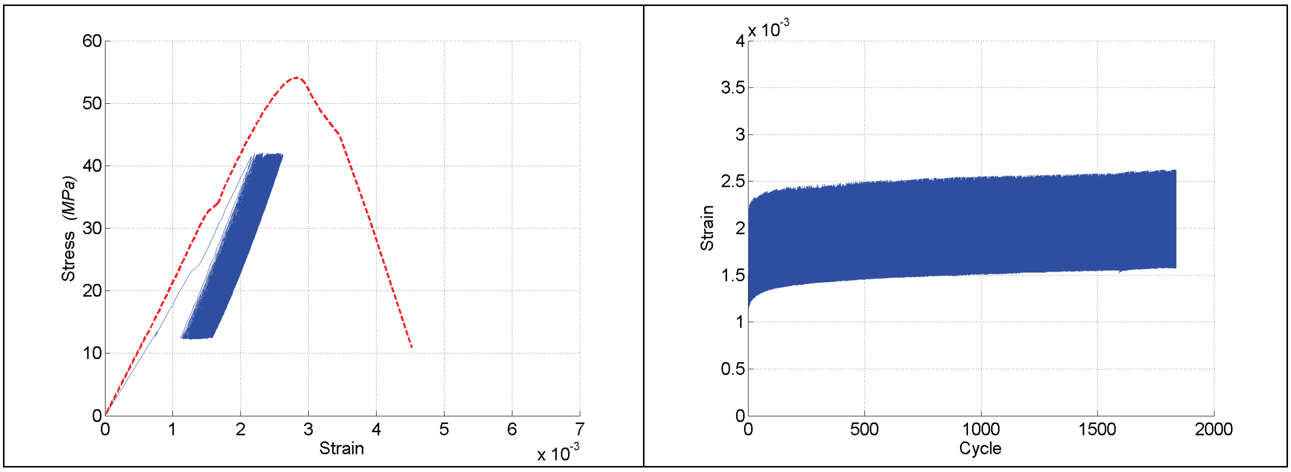

Fig. 10. On the left: fatigue stress strain behaviour of 50% RAC loaded between 25% and 75% of peak strength. On the right: strain development with increasing cycles

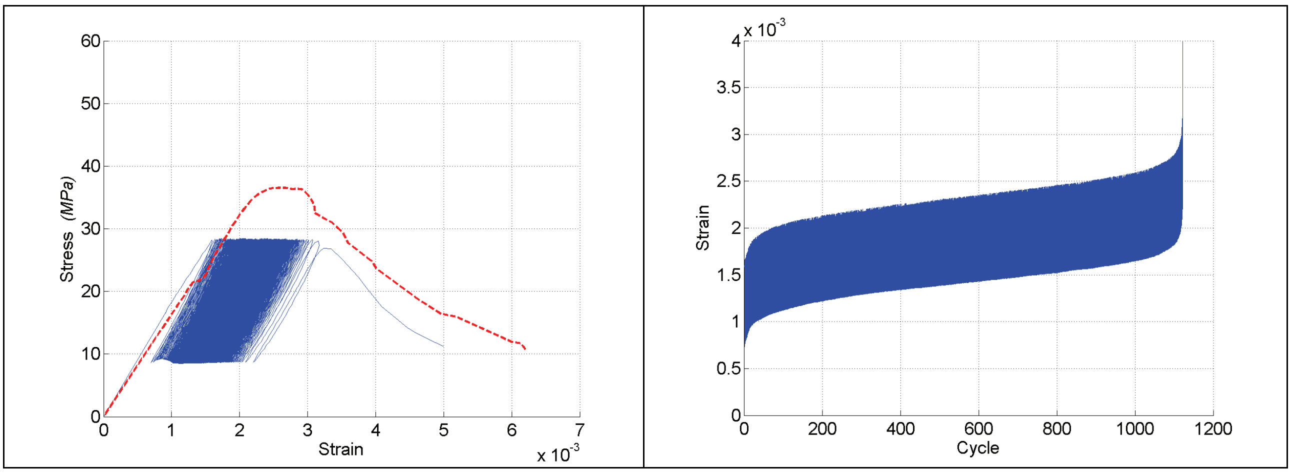

Fig. 11. On the left: fatigue stress strain behaviour of 100% RAC loaded between 25% and 75% of peak strength. On the right: strain development with increasing cycles

The fatigue behaviour of RAC exhibits characteristics and damage accumulation pattern similar to those available in literature for normal aggregate concrete. Nevertheless, as observed by other Authors the use of recycled aggregate as replacement of natural coarse aggregates in concrete seems be responsible of a reduction of the concrete fatigue life.

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