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Variability of the bond and mechanical properties of self-compacting concrete

Variabilidade da aderência e das propriedades mecânicas do concreto auto-adensável




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Abstract

This main objective of this research is to evaluate the variability of the mechanical properties (compressive strength, modulus of elasticity and tensile strength) and bond strength of the self-compacting concrete (SCC), with 50 MPa compressive strength at 28 days, varying the maximum aggregate size and the SCC fluidity. The tests were made in 15 x 30 cm concrete cylinders and in beams standardized by Rilem-Ceb-Fib (1973). In agreement with the obtained results, can be concluded that the variability of the self-compacting concrete is small for the modulus of elasticity and for the compressive strength, but the tensile strength presented a significant variability due to the failure mode. About the bond strength, the variability was small showing that the self-compacting concrete is reliable and possesses great potential for use in the civil construction.

Keywords: Self-compacting concrete, variability, hardened state, steel-concrete bond, beams, statistical analysis.

Resumo

Esta pesquisa tem como objetivo estudar a variabilidade das propriedades mecânicas (resistência à compressão, módulo de elasticidade longitudinal e resistência à tração) e da resistência de aderência do concreto auto-adensável (CAA), com resistência à compressão do concreto de 50 MPa aos 28 dias, variando o tamanho máximo do agregado graúdo e sua fluidez. Os ensaios foram realizados em corpos-de-prova de 15 x 30 cm e em vigas padronizadas de acordo com o Rilem-Ceb-Fib (1973). De acordo com os resultados obtidos, pode-se concluir que a variabilidade do concreto auto-adensável é pequena para o módulo de elasticidade e para a resistência à compressão e grande para a resistência à tração por causa do modo de ruptura do modelo. Com relação à resistência de aderência, a variabilidade foi pequena mostrando que o concreto auto-adensável é material confiável com grande potencial de utilização no mercado da construção civil.

Palavras-chave: concreto auto-adensável, variabilidade, estado endurecido, aderência aço-concreto, vigas, análise estatística.

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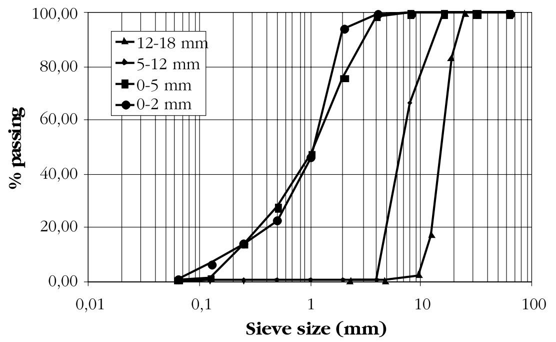
1. Introduction

Along the last years there was a great technological progress of the materials for the civil construction industry, resulting in the development of High Performance Concretes that do not need any mechanical vibration. The self-compacting concrete (SCC) had its origin in the need of more durable structures with economy of the work and time usually spent on concrete vibration.
An overall improvement in the constructive process is achieved when SCC is used, resulting in higher concrete quality, even for high reinforcement rates, as well as better safety and health for the workers[1-2].
As disadvantages, SCC needs a high level of control on the quality of the used materials (sand, coarse aggregate, filler, superplasticizer and cement) and on the adopted mix, since the concrete properties in the fresh state can be altered presenting excessive fluidity, segregation or excess of cohesion.
In this way, SCC can be defined as a concrete that is capable of flowing inside a formwork, passing through the reinforcement and filling it completely without any mechanical vibration. Due to this behavior, SCC can be classified as an advanced construction material. Its composition includes fine materials, offering the possibility of using powder of rejected substances that have no application in the industries. [3-4].
The mechanical properties of SCC are object of extensive experimental research, since the mechanical vibration is eliminated and SCC quality is based on its fluidity without any segregation. Like this, experimental studies to corroborate those expected properties are essential to guarantee the safe use of SCC in the construction industry [5-7].
Nowadays, there is a crescent interest about the variability of the materials that are being used to assure they present the needed quality. The studies about variability need a considerable number of repetitions to be truly representative of the studied phenomena. Elementary statistics concepts, like mean standard deviation and variation, can be used in this study. But if a better evaluation of the parameters affecting the materials properties is needed, more complex procedures of variance analysis can instead be used.
The use of statistics procedures to evaluate the materials behavior was always subject of experimental investigation, but with many contradictories conclusions. The main reason for that was the misuse of the procedures on the obtained results or the insufficient number of these results. Sometimes the chosen procedures were not adequate to the specific study. Or the number of replicas of a test was not sufficient to evaluate the repetition of the results.

Table 1 – Accepted limits of variability of concretecompressive strength as a function of the quality control

Quality control	Accepted limits for the standard deviation (18) (fc>27MPa)	Accepted limits for the coefficient of variation
A (excelent)	2.7	10%
B (average)	4.0	15%
C (poor)	5.4	20%

Figure 1 – Aggregate grading



To avoid variations, mean and standard deviation need a high number of samples to be calculated. The alternative procedure, that is to analyze the variance, involves a more detailed analysis of the parameters that can affect the results.

1.1 Objectives and research significance

Nowadays, there still remains some reluctance to use SCC, mainly due to its recent development (Japan, 1988 [1]), which turns it a not well known construction material. There is also a lack of experimental data about its behavior and not so many constructions in service using SCC to assure its quality and safety.
Besides, according to the technical literature little attention has been given to the variability of the concrete properties in general. There are few studies on this subject, some of them for concretes with fibers addition [9-13] and others focusing on the rheologic parameters [14-17].
So, the motivation for this research was the absence of reliable data regarding the variability of the SCC mechanical properties and steel bond.
The main objective is to show that SCC is as reliable as the conventional concrete to be used in the civil construction industry.
In order to achieve this, an experimental programme was performed in the *Laboratório de Tecnologia de Estructuras* do *Departamento de Ingeniería de la Construcción* (ETSECCPB-UPC/Barcelona) to study the variability of SCC properties in the hardened state. The studied parameters were compression strength, elasticity modulus and tension strength for different size of coarse aggregates, considering an age of 28 days. The variability of the steel-concrete bond was also studied by means of the Rilem standardized beam test [8]. These chosen parameters were analyzed from a statistic point-of-view through the calculation of mean, standard deviation, coefficient of variation and frequency.

1.2 Criteria for the analysis of results

To guarantee a high quality level, it is necessary to establish some parameters to determine the variation of the analyzed properties. This evaluation can be done by means of the standard deviation (S.D.) and the coefficient of variation (COV). S. D. is the most used procedure [18], but COV gives a better understanding and easiness of visualization, since it does not depend on the magnitude of

Table 2 – SCC mixes developed

	SCC1	SCC2	SCC3
V_{paste} (%)	38%	34.5%	35%
Void content (%)	29.2%	27.4%	27.4%
Cement (kg/m³)	362.5	329.0	333.8
Water (kg/m³)	181.3	164.8	166.9
Superplast. (kg/m³)	6.2	5.6	5.7
Filler (kg/m³)	108.7	98.7	100.1
Sand 1 (kg/m³)	710.9	607.1	602.5
Sand 2 (kg/m³)	397.8	339.7	337.1
Gravel 1 (kg/m³)	525.9	450.7	447.3
Gravel 2 (kg/m³)	-	330.0	328.5
Tests			
Temp. (°C) =	22	22	23
Humidity (%) =	66	78	66
Slump-flow			
T_{50} (s) =	1.0	1.5	1.0
D_e (cm) =	74.0	57.0	74.0
L-box			
T_{60} (s) =	1.0	3.0	1.0
Blocking=	1.0	0.7	0.95
V-funnel			
T_v (s) =	2.5	5.5	5.0
J-ring			
T_{50} (s) =	1.0	2.0	1.0
D_j (cm) =	74.25	55.5	73.5
Blocking=	1.0	0.77	1.0
Density			
ρ (kg/m³)	2400.41	2420.95	2425.21

the measured property. Table 1 shows the established criteria for this investigation.

The main reason to adopt the coefficient of variation in this research is the absence of information regarding the expected limits of the S.D. for the concrete elasticity modulus and compressive strength.

1.3 Analyzed statistical parameters

The chosen parameters used to analyze the variability of the SCC properties include mean (M), standard deviation (S.D.) and confidence interval (C.I.) [19].

More than 10 results (8 for the bond strength study) of each type of concrete were analyzed in-order to determine the considered parameters. Additionally, a Gaussian distribution of probabilities was obtained for the elasticity modulus and the bond strength.

It is worth to remind that the study of the SCC mechanical properties variability is a new approach in the attempt of establishes the reliability of this new construction material. For this initial study three mixes were considered.

2. Variability of the SCC mechanical properties

The designing method for SCC was based on the optimization of the paste composition and of the granular skeleton [3]. The optimization procedure takes into account the water-cement ratio and the superplasticizer content. For the granular skeleton the optimization consisted in obtaining the higher unitary mass or, in other words, the smaller void content. The used procedure was based in the dried compacting method applied to SCC [3].

The used cement was CEM II 42.5 (corresponding to a CP II) aiming to obtain a compressive strength of 50 MPa at 28 days. The filler and the aggregates were calcareous, and the filler had a particle diameter inferior to 0,125 µm [20]. Figure 2 shows the aggregate grading. The used superplasticizer was Glenium C303 SCC (policarboxylate based).

Two types of sand (1 and 2) with diameters of 0-2 mm and 0-5mm, and 2types of coarse aggregates (1 and 2) with diameters of 5-12 mm and 12-18 mm were used.

Tests on 30 specimens obeying the SCC acceptance criteria were per-

Table 3 – SCC1 variability at 28 days

Cylinders	E_{cm} (MPa)	f_c (MPa)	f_t (MPa)
1	36143.00	47.70	
2	38256.50	48.59	
3	36387.00	46.56	
4	37050.50	42.38	
5	36076.00	45.54	
6	35581.00	47.39	
7	36932.00	47.19	
8	37389.50	45.75	
9	36485.00	49.10	
10	37211.50	47.98	
11	35670.50	41.90	
12	36862.50		4.40
13	36504.50		2.64
14	36949.00		3.95
15	36183.50		4.06
16	35176.50		2.81
17	37292.00		3.38
18	35570.50		3.67
19	36416.00		4.45
20	36141.50		3.96
21	36514.00		4.00
22	35315.50		3.65
A	36459.45	46.37	3.72
S.D.	752.90	2.36	0.58
C.V. (%)	2.07%	5.08%	15.69%

Table 4 – SCC2 variability at 28 days

CP	E_{cm} (MPa)	f_c (MPa)	f_t (MPa)
1	39090.50	50.50	
2	39667.50	48.23	
3	40587.00	42.74*	
4	38570.00	50.70	
5	38323.50	50.62	
6	38612.50	50.62	
7	38389.00	49.21	
8	39285.50	49.48	
9	38860.00	49.59	
10	37984.00	40.98*	
11	38031.50	49.85	
12	39148.50	49.60	
13	38762.50		3.42
14	31483.00*		3.40
15	39736.00		3.27
16	31373.50*		4.45
17	40089.50		4.25
18	39332.50		3.57
19	39511.50		4.19
20	38915.00		3.17
21	38245.50		3.61
22	38982.00		3.80
23	38605.50		4.09
24	38894.50		3.51
A	38982.90	49.84	3.73
S.D.	659.22	0.79	0.42
C.V. (%)	1.69%	1.59%	11.32%

formed, with exception of the fluidity for one high cohesive mixture. Table 2 shows the SCC mixtures and their fresh state properties.

2.1 Cylinders tests

Each specimen was taken to a humid chamber (90%<UR<95%) for 27 days, having after the surface regularized for the tests.
The tests were performed in an Ibertest machine. It is worth to remind that the given values for SCC1, SCC2 and SCC3 had a statistical treatment. The values that, according to the probabilistic diagram were out of the normal distribution were eliminated.
Tables 3, 4 and 5 show the results for hardened properties of SCC1, SCC2 and SCC3, respectively.
Figures 2, 3 and 4 show the tests results for the elasticity modulus in relation to the compression and tension strength.

3. Variability of the SCC bond strength

For the low compressive strength concretes, it is expected that the SCC presents higher bond strength due to its better filling ability in comparison to conventional concretes.
However, when comparing low strength CC and SCC tests results, they usually present similar bond strength [21-23], except in places with high reinforcement rates, where SCC stands out [24].
Some authors [21-22] presented results on pull-out tests of steel bars using SCC and CC of similar properties. In the bond displacement behavior, they observed a small drop of the bond stress in the peak of the curve, and an increase of ductility after that.
Another researcher [25] observed the influence of the steel bar position during the casting process on the steel-concrete interface. Vertical and horizontal bars were tested, with the SCC specimens presenting similar behavior to the CC specimens, but with higher adhesion.
A study on the bond between steel bars and SCC and CC of similar compression strength in beams tests was also presented [26]. An adaptation of the Rilem beam test for bars of diameters less than 16mm was used to utilize available formworks. According to the authors, the beams presented fragile shear failure. About the bond strength reduction observed in [27], they attribute this result to the high content of fines of the considered mixture. And for adequately designed mixtures, they assure SCC presents bond strength similar to CC, but with fragile failure demanding specific

Table 5 – SCC3 variability at 28 days

CP	E_{cm} (MPa)	f_c (MPa)	f_t (MPa)
1	37856.50	44.47	
2	37745.00	43.34	
3	37953.00	38.08	
4	38776.50	43.53	
5	38238.50	42.82	
6	36497.50	43.46	
7	38449.00	45.99	
8	38039.50	39.72	
9	38821.00	41.19	
10	38095.00	43.47	
11	36728.00		3.75
12	38539.00		2.74
13	37612.50		2.44
14	39217.50		3.05
15	36765.00		2.47
16	35354.50		3.10
17	39695.00		3.59
18	39551.50		3.94
19	38669.00		3.12
20	37154.00		3.36
A	37987.88	42.61	3.16
S.D.	1085.72	2.33	0.51
C.V. (%)	2.86%	5.46%	16.25%

procedures. As conclusions, they recommend the use of SCC in structural repair, and also to increase the durability of the structures.

The fragile failure of the steel-concrete connection in SCC elements can be attributed to its better filling ability in relation to CC. A better filling of the formworks results in a better involvement of the bars. As a consequence, an increase of adhesion and confinement could be attained, provoking higher bond strength, but with fragile failure.

A preliminary study about bond strength in pull-out tests in accordance with Rilem [8], using SCC and CC of same compression strength is presented in [28-30]. According to the results, the behavior of both concretes is similar, but for specimens with 16 mm bars, CC presented higher bond strength. And, unlike [26], once the compression strength is the same, the concrete type (SCC or CC) does not affect the concrete prism failure mode

Table 6 – Hardened properties of each mix at 28 days

	SCC1	SCC2	SCC3
$f_{c,28}$ (MPa)	51.77	52.61	53.75
$E_{c,28}$(GPa)	37.31	35.91	38.41
$f_{t,28}$ (MPa)	3.10	3.23	2.28

3.1 Beams tests

The tests for the evaluation of bond strength were designed to use steel formworks available in the *Laboratorio de Tecnología de Estructuras,* where the tests were performed. For each series 8 beams were molded, as seen in Figure 5.

The reinforcement of the beams was the one established by Rilem [8] and [31], with small adjustment in the height to guarantee the 1 cm concrete cover.

Table 6 shows the values of the mechanical properties for the used SCCs.

Table 7 shows the obtained results for Ultimate Force and corresponding slope (δ_u) for each test.

Figure 2 – Hardened properties variability of SCC1 mix

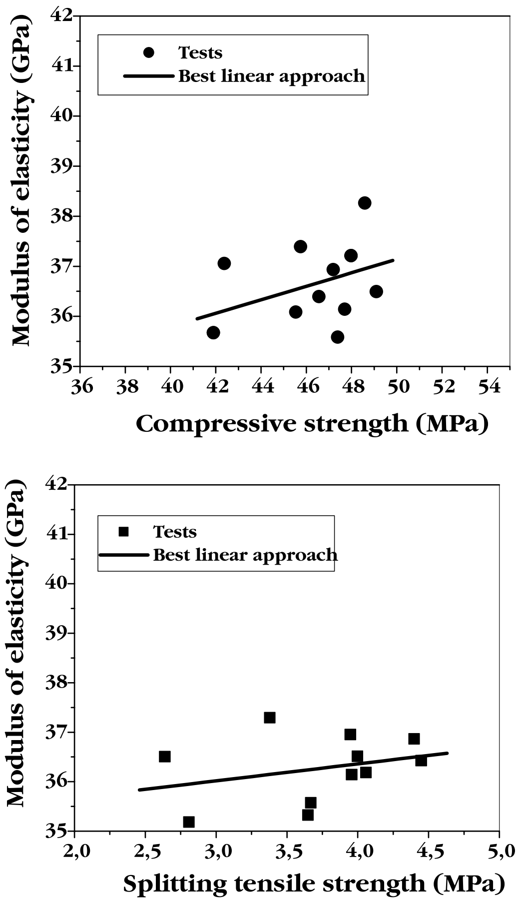


Figure 3 – Hardened properties variability of SCC2 mix

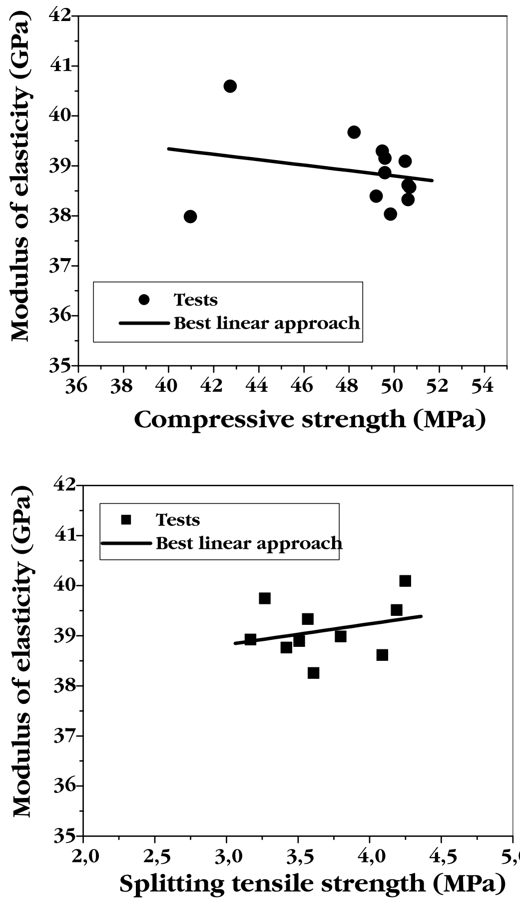
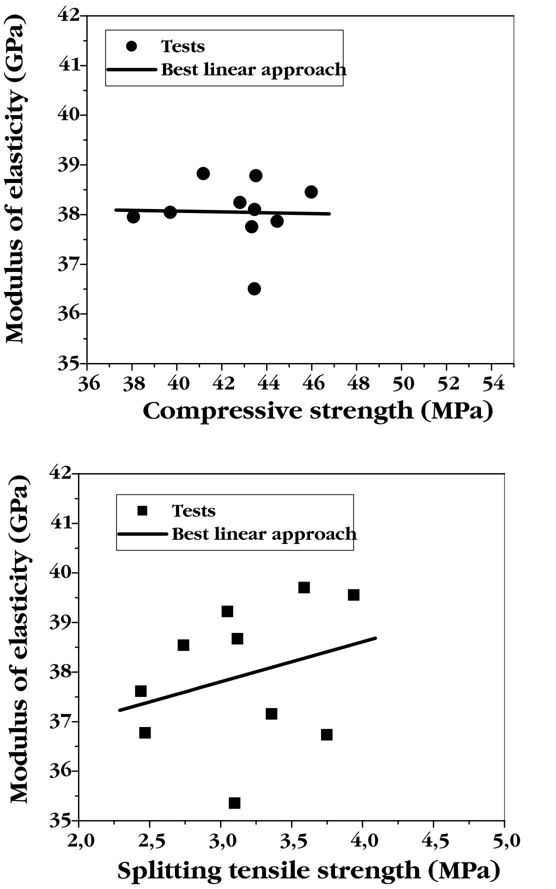


Figure 6 shows the variation of the results of the beam tests, for each series.
In the beam tests, for all series, the failure mode was associated to the yielding of the steel bar in the middle section, in parallel to the concrete crushing between the support plate and the steel bar (Figure 7).

Figure 4 – Hardened properties variability of SCC3 mix



4. Analysis of the results

Regarding the variability of the SCC in the hardened state, it was observed that many parameters can affect the compression strength and the elasticity modulus, such as the specimen surface regularization and the amount of incorporated air.
The tension tests were characterized by concrete splitting and fragile failure. This behavior can affect the mean of the results and lead to a high variability, as can be seen in the tests.
Figure 8 shows the variation of the Elasticity Modulus regarding density, compressive and tension strength of each tested specimen. According to the obtained results, the more fluid mixtures presented a variation superior to the less fluid one (SCC2). The variability was smaller when discarding specimens' results after a statistical analysis was done. As commented before, the possible reasons for this variability are the specimen surface treatment (higher possibility), the voids in the specimen surface (possible) or the misuse of the equipment (less possible.)

Table 7 – Failure load and vertical displacement for each beam series

SCC1		SCC2		SCC3	
P_u (kN)	δ_u (mm)	P_u (kN)	δ_u (mm)	P_u (kN)	d_u (mm)
---	---	85.26	17.02	88.32	24.92
86.71	22.67	83.35	13.82	92.03	28.44
85.99	18.38	88.90	25.15	92.85	25.63
92.33	29.68	84.43	26.48	90.74	25.55
82.12	25.86	89.88	25.93	98.42	25.43
85.44	28.74	83.63	25.34	88.17	22.92
99.22	23.72	84.13	24.64	86.00	26.82
92.49	28.33	88.62	23.38	92.61	21.52

Figure 5 – Dimensions of the used bean for the bond stress test (in cm.)

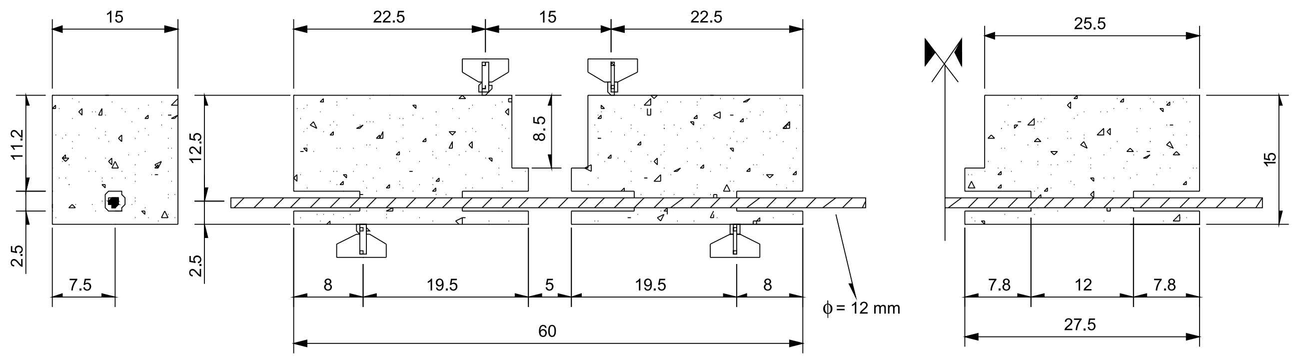


Figure 6 – Bond stress variability for SCC1, SCC2 e SCC3 series

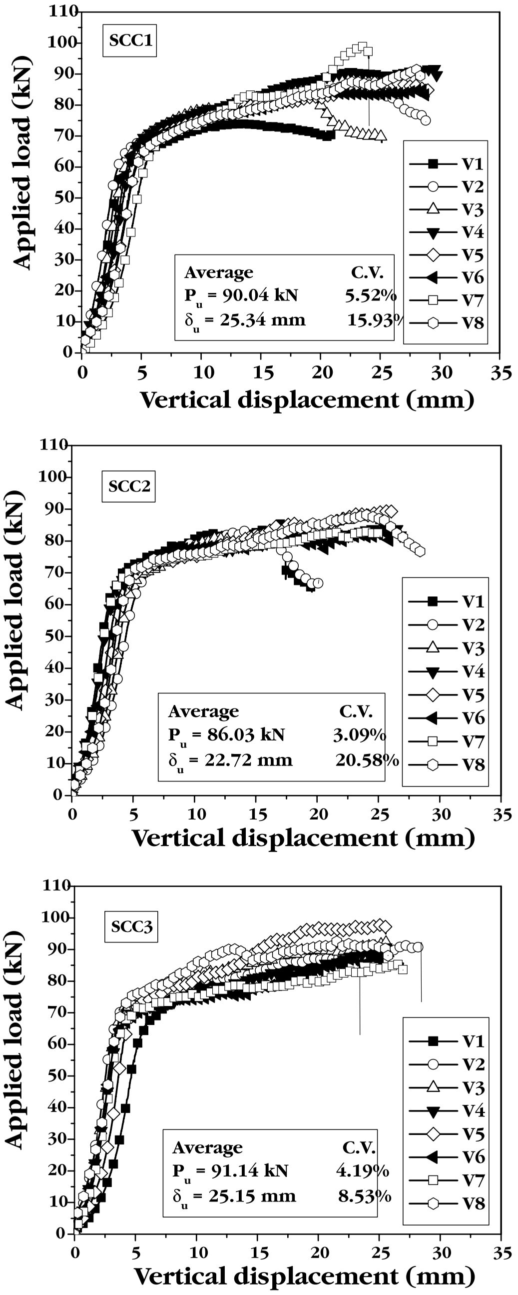
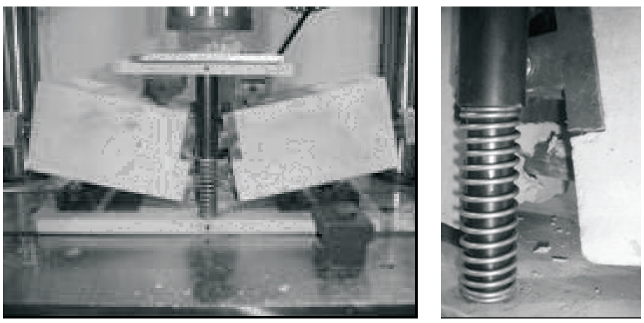


Figure 7 – Beam specimen at test and failure mode



According to Figure 8, as density increases, elasticity modulus increases. It was also observed that as compression strength increases, elasticity modulus also increases, with small variability. However, when tension strength increases, even for very high values, this does not mean an increase in the elasticity modulus. This behavior reinforces the previous conclusion about the influence of

Figure 8 – Variability of the modulus of elasticity compared to density, compressive strength and splitting tensile strength of each specimen

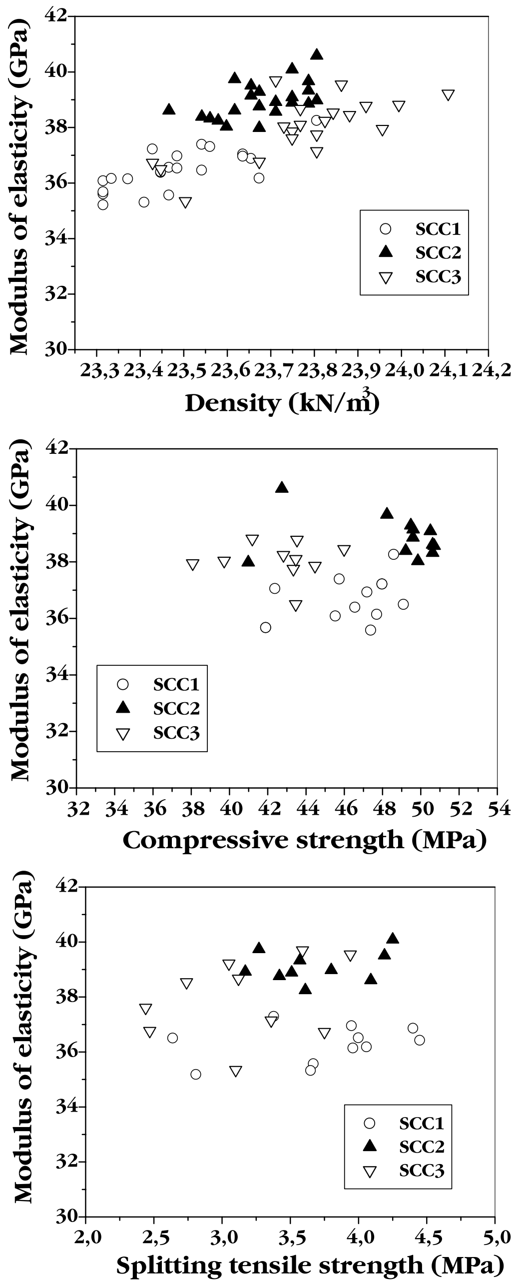


Table 8 – Confidence level for the modulus of elasticity

	SCC1	SCC2	SCC3
A (GPa)	34.46	38.98	37.99
S.D. (GPa)	0.75	0.66	1.08
Freedom level	21	21	19
Inferior Limit (GPa)	34.90	37.61	35.73
Superior Limit (GPa)	38.02	40.35	40.19

the failure mode on the tension strength, as well as on the high dispersion of the results for each series.

The indirect compression test or Brazilian Test presents high variability due to its failure mode, which depends on the support for the specimen in the test apparatus.

The variability regarding fluidity, showed in Figure 8, can be related to the velocity of the formwork filling. The faster the SCC is poured, the higher the possibility of avoiding the air escaping. This can result in bubbles of air being incorporated to the concrete, and a less quality concrete, possibility that needs more tests to be confirmed.

A statistic analysis of the obtained data was done, and means, standard deviation and coefficient of variation were calculated for each series.

Table 8 shows the confidence interval for the elasticity modulus considering the series SCC1, SCC2 and SCC3.

According to Table 8, the confidence interval of 95% was established for the mean of the elasticity modulus values, for a number up to 19 samples, and none of the specimens was out of this interval, showing a small variation in the results. Figure 9 shows the results in a plot using Gaussian probabilistic scale.

As expected, it can be seen in the Figure 9 that the results have a normal distribution.

Figure 10 represents the plot of cumulative frequency for the modulus of elasticity of the series.

Regarding he beam tests, the variability was inferior to 10%, assuring the adequacy of the test to analyze the bond strength. Figure 11 shows the mean of the results for the applied load *vs* vertical displacement and bond stress *vs* slip behavior, considering the 3 series of beam tests.

The small variability of the results can be verified in the figure. The obtained slips are small, what is coherent with the high strain detected in the steel bar, as showed in Figure 7. The measured slip was similar for all tests, and always smaller than 3.0 mm, the limit value established by Rilem-Ceb-Fip [8].

Figure 12 presents the variation of the applied force with the displacement, for each beam test, and the variation of bond strength with slip for the three series of beams.

According to Figure 12, the bond strength decreases when the slip increases. A possible explanation for this behavior can be attributed to the interference of the reaction system of steel bar on the plate of the hinge, with the yielding of the bar. Another reason could be the value of the elasticity modulus, mainly for series SCC2 that presented higher slip.

The statistical evaluation of the beams tests results by means of Gauss distribution and frequency analysis does not seem to be adequate due to the small number of samples considered in these tests (8 for each series). However, since the coefficient of variation was inferior to 10%, this kind of analysis was done with the objective of verifying if the results are representatives and if the normal distribution can be used. Figure 13 presents the results of the cumulative frequency distribution for the applied force, for the 3 series.

Figure 9 – Representation of the modulus of elasticity in probabilistic paper

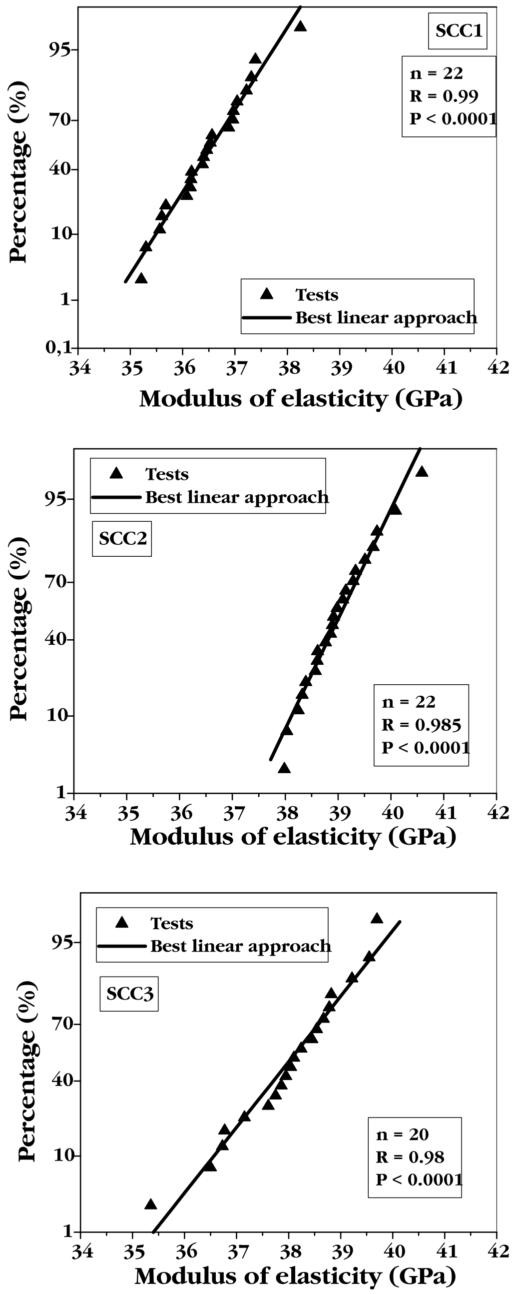


Figure 14 represents the frequency distribution of the ultimate load of the tests, for each series.
Table 9 presents the confidence interval for the failure load of the beam tests, for the three series SCC1, SCC2 e SCC3.
According to the results, a confidence interval of 95% was established for the mean of the failure load values, in the beam tests. Since the samples number was over than 7, and no one was out of the interval, it can be concluded that the variation of the results was small.
The analysis of these plots shows that the beam tests can be representative to measure bond strength, and the obtained results present small variability.

5. Conclusions

The main objective of this experimental investigation was to analyze, from a statistical point-of-view, the variability of the mechanical properties of the self compacting concrete. The considered properties were compression/tension strength and modulus of elasticitymeasured from

Figure 10 – Normal distribution function and frequency for the modulus of elasticity of each series

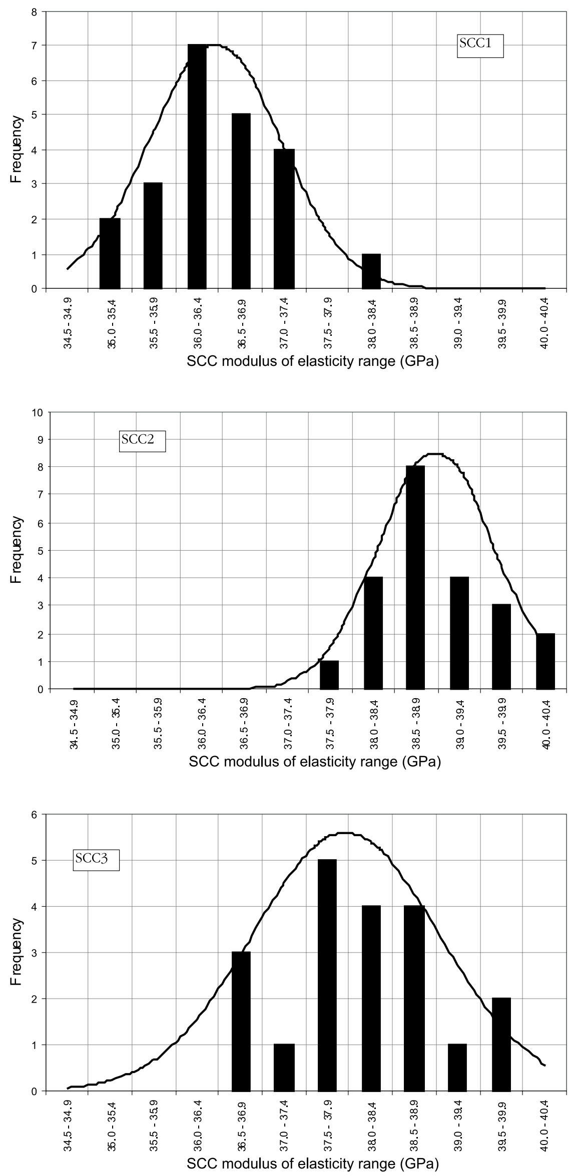
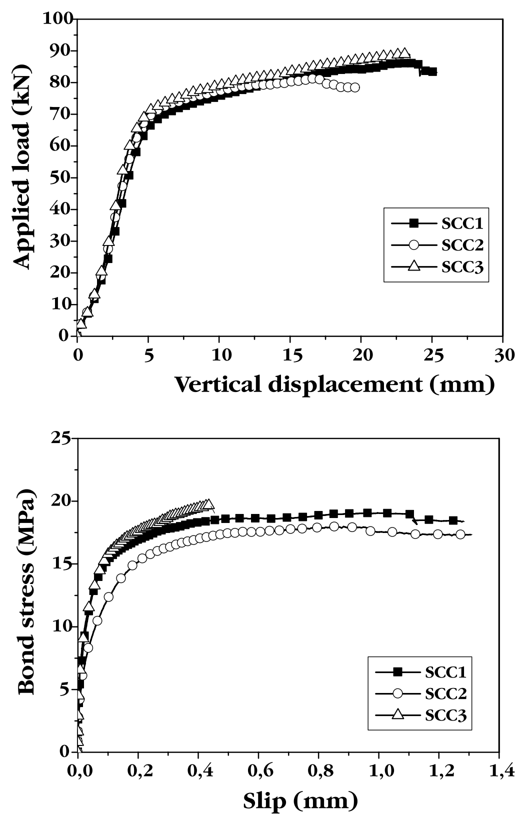


Table 9 – Confidence level for the failure load in beam test (in kN)

	SCC1	SCC2	SCC3
A (kN)	90.04	86.03	91.14
S.D. (kN)	4.97	2.66	3.82
Freedom level	6	7	7
Inferior Limit (kN)	77.89	79.74	82.10
Superior Limit (kN)	102.20	92.31	100.18

Figure 11 – Comparison of the series for applied load vs. vertical displacement and bond stress vs. slip



tests on 15x30 cm cylindrical specimens, and bond strength obtained with beam tests, adapted from the standard beam test of the Rilem-Ceb-Fip [8]. All tests were performed at 28 days, in the *Laboratorio de Tecnología de Estructuras* from the *Departamento de Ingeniería de la Construcción,* in Barcelona (Spain). Since the results are affected by external parameters, it is worth to comment that the following conclusions are valid for the materials and conditions of the research.

Regarding the variability of the properties of SCC in the hardened state at 28 days, proposed in this paper, the study was divided in 2 parts. In the first one, the main mechanical properties that are tension and compression strength and modulus of elasticitywere considered. The second part studied the bond strength for the same SSC considered in the previous part of the research. According to the observed results, for the first part it was verified that:

- In the compression tests, external parameters can affect the results. The quality of the loaded surface of the specimens is very important for the results. Therefore, usual procedures used for regularization of the surface can locally damage the specimen worsening the results. Besides, the voids produced by the air incorporated during cast operations also can worse the specimens' performance.
- For the tension tests, the observed variability was a consequence of the failure mode presented by the specimen.
- The 3 series of SCC presented a behavior similar to the CC, with a confidence interval of 95%. The variability was inferior to 10%, except for the tension strength, mainly due to the considered test (Brazilian Test).

Regarding the beam tests used to evaluate bond strength, it can be concluded that:

Figura 12 – Test results variation for the beam series

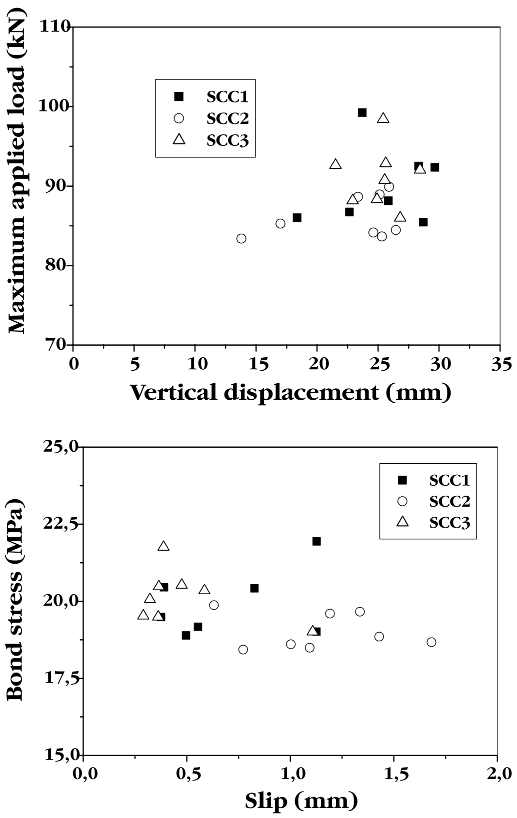
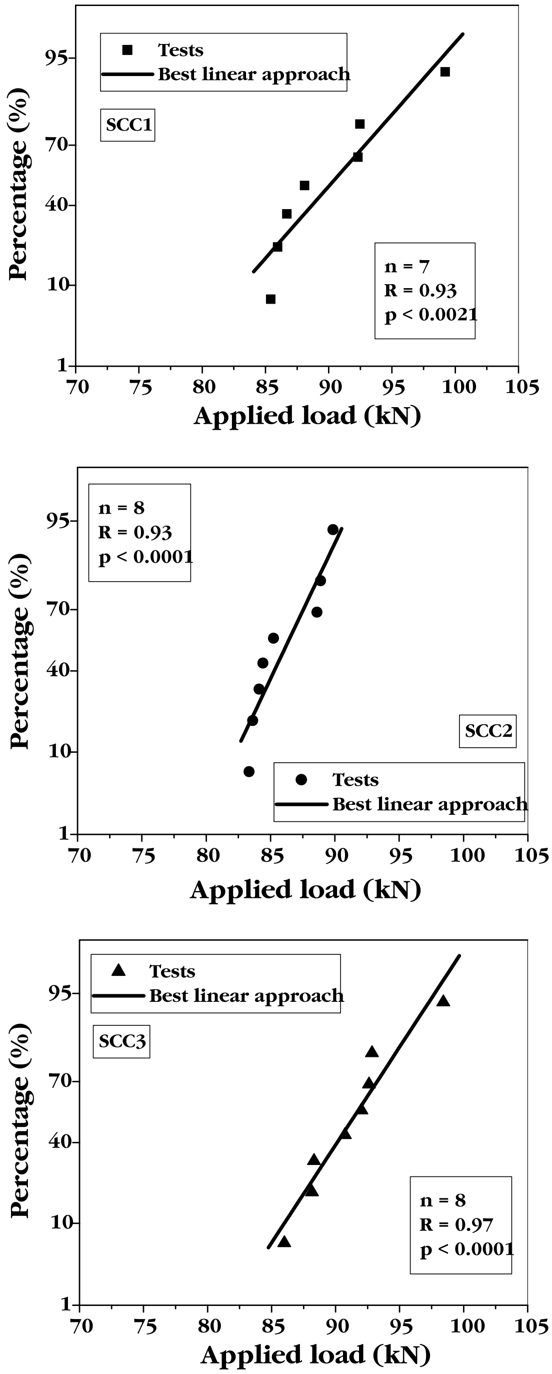
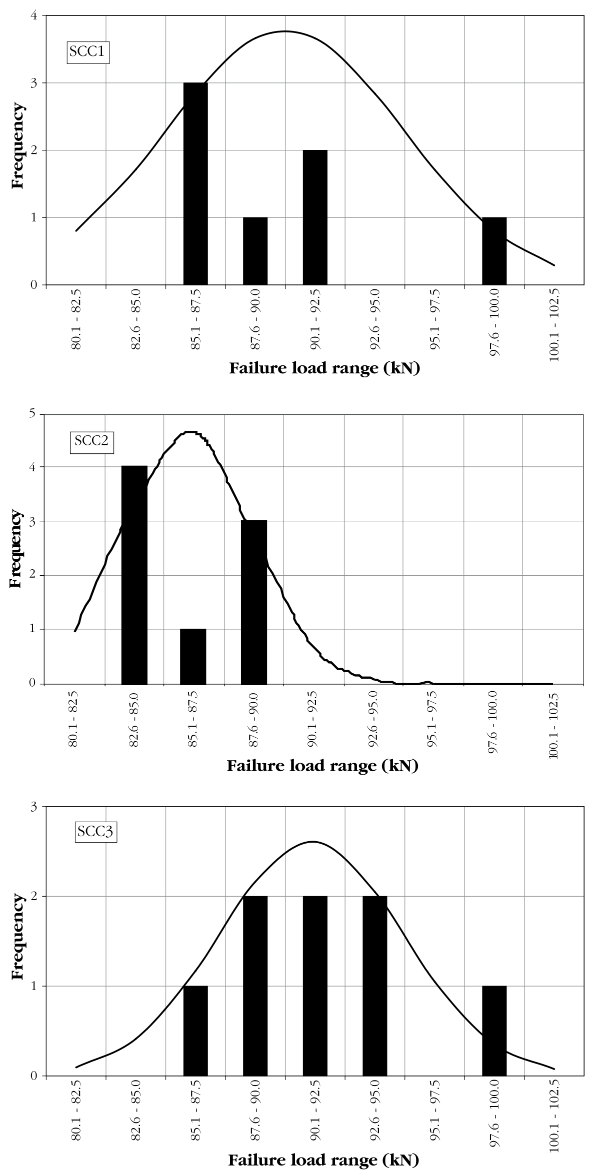


Figure 13 – Representation of the failure load in probabilistic paper



- The bond resistance was not affected by the SCC lack of fluidity. According to the done observations, however, the aspect of the beams cast with this specific concrete was characterized by the presence of voids and high porosity in the surface. This could possibly result in fragility regarding the attack of aggressive substances, as the chlorides.
- The bond resistance is improved when the modulus of elasticity increases. In this way, the high performance concretes with presence of fibers, high strength and low porosity are also the ideal to guarantee a good bond resistance and consequent safety for the structural elements.

Figure 14 – Normal distribution function and frequency for the failure load of each series



- On the other hand, high performance concretes have a fragile rupture of the bond connection. Unless some confinement reinforcement is provided, the splitting of the concrete surrounding the bar will occur, as the concrete tension strength is reached. And the desirable failure mode, with yielding or slip of the bar, will not occur.
- The size of coarse aggregate (depending on its origin) has a strong influence in the bond resistance, since it affects the SCC elasticity modulus.
- The behavior of the beams was similar in the 3 series of tests, even considering the low fluidity of SCC1 series.

In addition to the presented conclusions, some final comments can be done.

Even considering the bad appearance of the specimen made of low the fluidity concrete, its behavior was similar to the others. Figure 15 presents the aspect of the beams made of low fluidity and high fluidity concretes.

Regarding the tests procedures, the limits established by Rilem-Ceb-Fip [8] for maximum slip of 3.0 mm and range of concrete compression strength from 22,5 till 27,5 MPa are very critical. When high strength concretes are used, the slip is reduced due to the confinement effect promoted by both concrete and reinforcement. As observed in the tests, the failure occurred due to the yielding of the central point of the steel bar and the stresses concentration in the region of concrete between the bar and the hinge plate. Since the concrete compression strength was 50 MPa, the steel-concrete interface was extremely rigid. This caused the yielding of the bar with small slip in the bonded zone. This comment can be refuted, since the beam test presents some particularities that can affect the obtained results. Figure 16 shows the sequence of the beam test. By means of a rudimentary strut-and-tie model, it can be observed that the path of the stresses from the applied force to the supports goes through the bonded zone.

As final comment, based on the obtained results and respecting the limitations of the study, it can be concluded that self-compacting concretes have small variability, and can be used in the civil construction industries.

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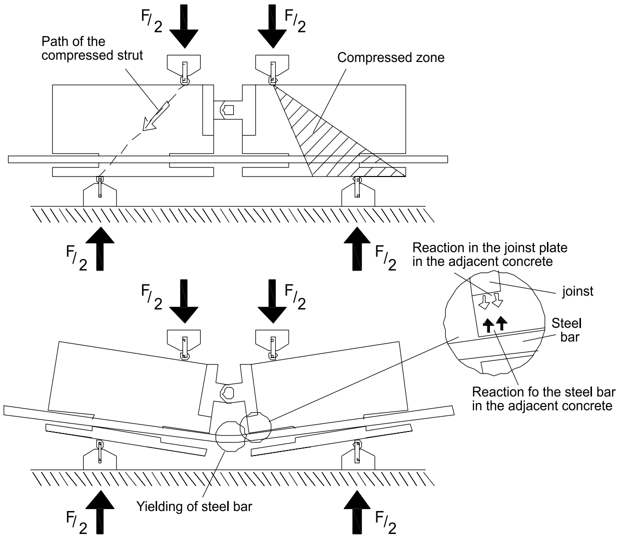
Figure 15– Beam specimen with los fluidity (rigth) and specimen with best fluidity (left)

Figura 16– Peculiarity of beam test



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