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TTI Ltd. (author, file)	IMLR
Millfield Enterprises (Manufacturing) Ltd.	John Dodd

Contents

1 Introduction

This report presents the results for compression testing which was undertaken on six resin cubes supplied to TTI Testing by Millfield Enterprises Ltd for their client Baudin Chateauneuf, (job reference 15277). It was requested to test the cubes in accordance with DNV-OS-E304 to determine the Barcol hardness, density, failure stress and Young's modulus.

This document sets out the measurements and results of the testing undertaken by TTI Testing Ltd. for Millfield Enterprises Ltd. in assessment of the cube properties.

2 Samples

A set of samples (nominal cube side length 40 mm) was supplied to TTI Testing by Millfield Enterprises Ltd. The cubes had previously been conditioned by heating in an oven at 80°C for 2 hours, and were numbered arbitrarily 1 to 6 inclusive.

3 Test Procedure

3.1 General preparation

On receipt, the cubes were machined to remove the resin rich layer and to provide parallel faces suitable for compression testing.

3.2 Compressive strength and Modulus of elasticity

TTI Testing's 250 kN machine (serial number 80184) was used for the compression tests. This machine is a universal testing machine, with main parameters listed in Table 3.1. A copy of the calibration certificate for this machine is presented in Appendix A.

Parameter	
Load capacity (kN)	± 250
Actuator stroke (mm)	150
Adjustable cross head for slack removal	Y
Maximum 'day light' below crosshead (mm)	1250
Controller	M9500 SERIES
Fatigue rated	Y

Table 3.1: Main parameters of the 250 kN testing machine.

- The ultimate compressive strength was taken as the captured maximum compressive load displayed on the machine controller.
- The Young's modulus was determined from the load-stroke data collected by proprietary software on a computer connected to the machine controller. Data was gathered at 0.1 s intervals.

Figure 3.1 presents a typical load-stroke plot for a compression test on a resin cube. The Young's Modulus, E, may be derived using this graph and in accordance with equation 3.1.

$$E = \frac{F}{\Delta l} \times \frac{l_0}{A} \tag{3.1}$$

Where F is Load applied over which the strain is measured [N];

Δl is the change in specimen length over the load range [mm];

l_0 is the initial specimen length [mm]; and,

A is the specimen area [mm^2]

The gradient of the load-stroke relationship (Figure 3.1) gives F / Δl, and l_0 and A are the measured length and cross-sectional area for each cube determined before testing.

Each load-stroke plot was corrected for the machine stiffness to give the intrinsic behaviour of the resin cube.

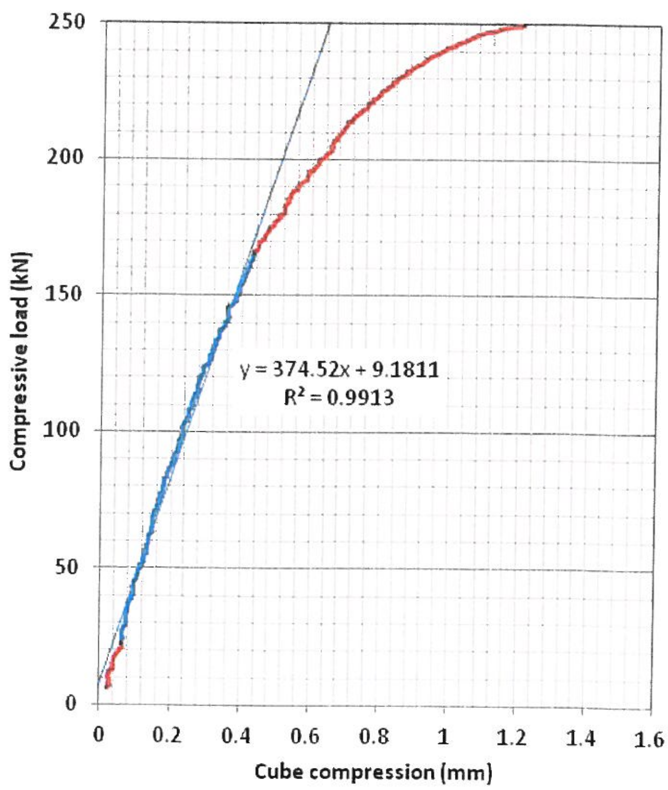

Figure 3.1: Example load-stroke relationship for a compression test on a resin cube used to determine the material Modulus of Elasticity.

3.3 *Barcol hardness*

Barcol hardness testing was conducted in accordance with ASTM D 2583. Figure 3.2 shows a resin cube being tested with a Barcol Hardness tester.

Six readings were taken from each sample. If one of the readings was inconsistent with the other five data points this reading could be dropped and an average value taken of the remaining five points.

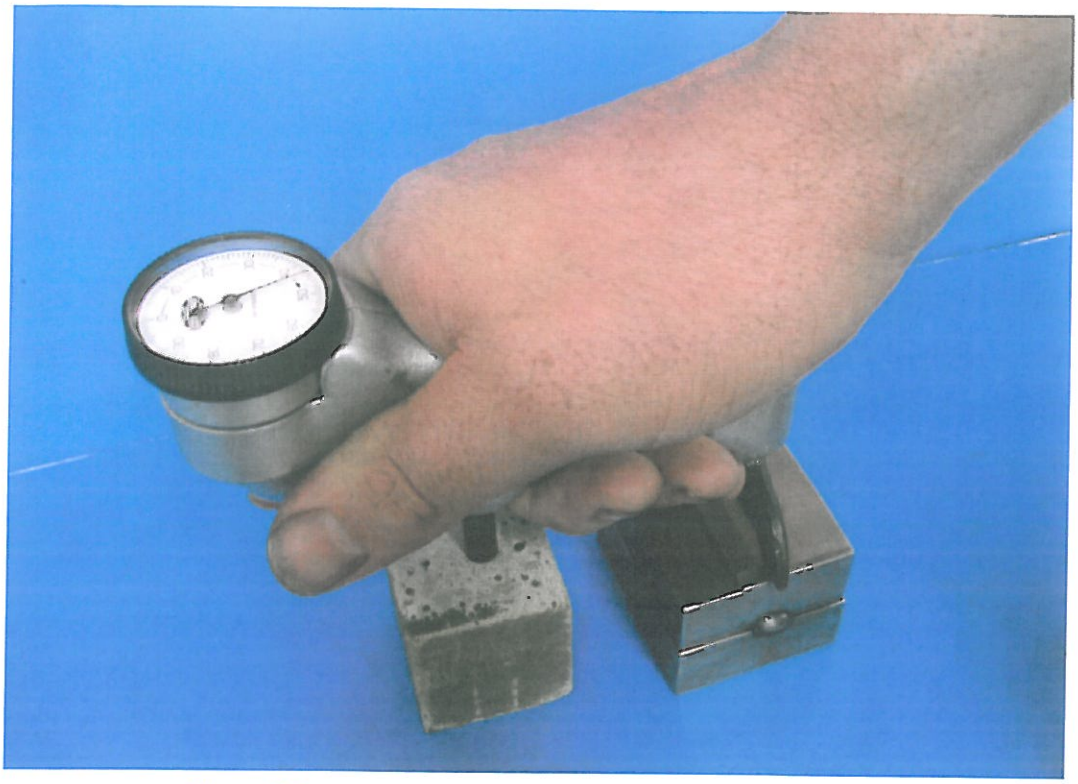

Figure 3.2: Use of a Barcol Hardness tester on a resin cube.

3.4 *Specific gravity*

The specific gravity of the mix was determined for each of the cubes (after machining). The linear dimensions of the cube were measured using digital callipers accurate to 0.01 mm, and the mass of the cube using digital scales accurate to ±0.01 g.

4 Results

4.1 Compression testing and Modulus of Elasticity

Table 4.1 summarises the results of the compression strength and modulus of elasticity tests which were undertaken on the six cubes.

Appendix B presents the load-stroke plots for each of the cubes from which the Modulus of Elasticity, E, was determined in accordance with equation 3.1.

4.2 Barcol Hardness and Specific Gravity

Table 4.2 presents the measurements and results for the Barcol Hardness testing.

	sample dimensions							
sample no.	width A	breadth B	height C	weight	relative density	compressive failure load	Nom. Failure stress	Modulus of Elasticity
(-)	(mm)	(mm)	(mm)	(g)	(-)	(kN)	(N/mm^2)	(N/mm^2)
1	39.60	39.60	38.48	110.38	1.83	243.90	155.5	9,164
2	39.66	39.58	38.66	110.92	1.83	246.80	157.2	8,989
3	39.56	39.59	38.84	111.35	1.83	250.10	159.7	9,767
4	39.57	39.59	38.82	111.41	1.83	250.00	159.6	9,710
5	39.55	39.58	38.81	111.25	1.83	248.90	159.0	9,146
6	39.57	39.58	38.84	111.51	1.83	247.00	157.7	10,424
Average					**1.83**		**158.1**	**9,533**
Standard Dev.					**0.002**		**1.62**	**541**

For ease of reference, the lowest values obtained for the failure stress and Modulus of Elasticity have been highlighted by the blue shading. These figures are well in excess of the values of 100 N/mm^2 and 6,000 N/mm^2 resp. stipulated by DNV-OS-304.

Table 4.1: Summary of the results and measurements taken during the compression and E-modulus testing of the resin cube samples.

Sample No.	width	breadth	height	weight	Specific Gravity	Barcol hardness						
					(SG)	1	2	3	4	5	6	Average
(-)	(mm)	(mm)	(mm)	(g)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
1	39.60	39.60	38.48	110.38	**1.83**	43	45	44	45	43	45	**44**
2	39.66	39.58	38.66	110.92	**1.83**	43	43	44	44	42	43	**43**
3	39.56	39.59	38.84	111.35	**1.83**	46	44	45	44	43	43	**44**
4	39.57	39.59	38.82	111.41	**1.83**	43	44	43	42	43	44	**43**
5	39.55	39.58	38.81	111.25	**1.83**	43	42	43	44	46	43	**44**
6	39.57	39.58	38.84	111.51	**1.83**	46	42	44	46	45	44	**45**
Average					**1.83**							
Standard Dev.					**0.002**							

Note, for ease of reference, the lowest values of Barcol hardness obtained for each of the cubes have been highlighted by the blue shading. These figures are all in excess of the minimum value of 36 stipulated by DNV-OS-304.

Table 4.2: Summary of results for the Barcol hardness and Specific Gravity testing of the resin cube samples.

5 Discussion and Conclusions

1. The relative density of the cubes was measured as 1.83 for all cubes. The DNV-OS – E304 (§D101 Table 1) specifies a range of 1.55 – 1.95. Therefore the cubes may be said to satisfy the requirement of the standard in this respect.
2. Measurements of the Barcol hardness of the six cubes were in the range 42 – 46. All readings were in excess of the minimum value of 36 specified in DNV-OS –E304 (§D101 Table 1). Therefore the cubes may be said to satisfy the requirement of the standard in this respect.
3. The compressive strength for the six cubes were in the range 155.5 – 159.7 N/mm^2, with an average value of 158.1 N/mm^2. This value is well in excess of the 100 N/mm^2 specified in DNV-OS –E304 (§D101 Table 1). Therefore the cubes may be said to satisfy the requirement of the standard in this respect.
4. The Young's Modulus for the six cubes was in the range 8,989 – 10,424 N/mm^2. All values were well in excess of the min. 6,000 N/mm^2 specified in DNV-OS –E304 (§D101 Table 1). Therefore the cubes may be said to satisfy the requirement of the standard in this respect.

6 References

[1] **Offshore Standard DNV–OS–E304** Offshore moorings steel wire ropes, April 2009, Det Norske Veritas, Høvik, Norway.

[2] **ASTM D2583-07** Standard test method for indentation hardness of rigid plastics by means of a Barcol impressor, ASTM International, West Conshohocken, PA, 2007, DOI: 10.1520/D2583-07, www.astm.org.

Appendix A – Calibration certificate for 250 kN machine

CERTIFICATE OF CALIBRATION

ISSUED BY ZWICK TESTING MACHINES LIMITED

DATE OF ISSUE 11 October 2012
CERTIFICATE NUMBER 1210-1838

UKAS CALIBRATION

0167

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Zwick / Roell

APPROVED SIGNATORY

P. J. Morris,
M. C. Marchbank

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FOR	TTI Testing Ltd		
LOCATION	Unit 2,Beadle Industrial Estate, Hithercroft Road, Wallingford, Oxfordshire, OX10 9EZ.		
DESCRIPTION	A 250 kN testing machine having one range and using the Computer / M9500, Serial No 74807 as display		
MACHINE TYPE	Dartec 250 RE	**SERIAL NO.**	80184
YEAR OF MANUFACTURE	Not Known		
LOAD CELL CAPACITY	250 kN	**SERIAL NO.**	80184A
DATE OF VERIFICATION	26 September 2012		

CLASSIFICATION:

The above testing machine has been verified in tension and compression for increasing forces only, to BS EN ISO 7500-1 : 2004 using verification equipment calibrated to BS EN ISO 376 .

The machine complied with the requirements of the Standard for the following classification and ranges:

These results are as found

250 kN Range	**Class**	**1.0**	**Tension**	**250 kN down to 2.5 kN**
250 kN Range	**Class**	**0.5**	**Compression**	**250 kN down to 5.0 kN**
250 kN Range	**Class**	**1.0**	**Compression**	**250 kN down to 2.5 kN**

Certified.......................................

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

CERTIFICATE OF CALIBRATION

UKAS ACCREDITED CALIBRATION LABORATORY No : 0167

CERTIFICATE NUMBER
1210-1838

VERIFICATION EQUIPMENT

The following equipment calibrated to BS EN ISO 376 was used to effect the verification.

250 kN Tension and Compression load cell	Serial No. 074830059	Certificate No. 3824	Dated 26 June 2012
20 kN Tension and Compression load cell	Serial No. 132975	Certificate No. 2885	Dated 12 October 2010

The class of the verification equipment was equal to or better than the class to which this testing machine has been verified.

NOTE. The expiry date of the above certificates of calibration for the proving device is 26 months from the above given dates.

METHOD

When using the proving device, from 250 kN down to 2.5 kN, the indicated force method was used to effect the verification.

Three verification tests were made on each range.

No accessories were fitted.

MEASUREMENTS

1. The testing machine satisified the requirements of BS EN ISO 7500-1 : 2004 in respect to the relative error of accuracy, repeatability, zero and resolution (see Table 2 of the standard).

2. The ambient temperature at the time of verification was 21.1°C

NOTE

Clause 9 of BS EN ISO 7500-1 states that: The time between two verifications is dependant on the type of testing machine, the standard of maintenance and amount of use. Unless otherwise specified, it is recommended that the verification shall be carried out at intervals not exceeding 12 months.

The machine shall in any case be reverified if it has been dismantled for moving or subjected to major repair or adjustment

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements

CERTIFICATE OF CALIBRATION

UKAS ACCREDITED CALIBRATION LABORATORY NO 0167

CERTIFICATE NUMBER
1210 1838

Table of Results - Tension

Verification Devices

Nominal	Relative Error %	Uncertainty%
2.500 kN	0.42	0.32
5.000 kN	0.28	0.25
5.000 kN	0.67	0.26
12.500 kN	0.47	0.24
25.000 kN	0.43	0.22
50.000 kN	0.42	0.22
100.000 kN	0.41	0.22
150.000 kN	0.46	0.22
200.000 kN	0.49	0.22
250.000 kN	0.55	0.22

NOTE

The relative error quoted is the difference between the true value expected from the verification device(s) at the force loading values indicated by the machine in column 1 and the mean of three readings taken from the device(s) at those points.
The uncertainty calculation made at each force reading is indicated in column 3.
The uncertainties stated above refer to the values obtained during verification and make no allowances for factors such as long term drift, temperature and alignment effects - the influences of such factors should be taken into account by the user of the testing machine

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements

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CERTIFICATE NUMBER
1210-1838

UKAS ACCREDITED CALIBRATION LABORATORY NO 0167

Table of Results - Compression

Verification Devices

Nominal	Relative Error %	Uncertainty%
2.500 kN	-0.78	0.32
5.000 kN	-0.22	0.25
5.000 kN	-0.42	0.25
12.500 kN	-0.10	0.23
25.000 kN	0.03	0.22
50.000 kN	0.07	0.22
100.000 kN	0.05	0.22
150.000 kN	0.01	0.22
200.000 kN	-0.01	0.22
250.000 kN	-0.04	0.22

NOTE

The relative error quoted is the difference between the true value expected from the verification device(s) at the force loading values indicated by the machine in column 1 and the mean of three readings taken from the device(s) at those points. The uncertainty calculation made at each force reading is indicated in column 3.
The uncertainties stated above refer to the values obtained during verification and make no allowances for factors such as long term drift, temperature and alignment effects - the influences of such factors should be taken into account by the user of the testing machine.

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

Appendix B – Load-stroke plots for resin cubes

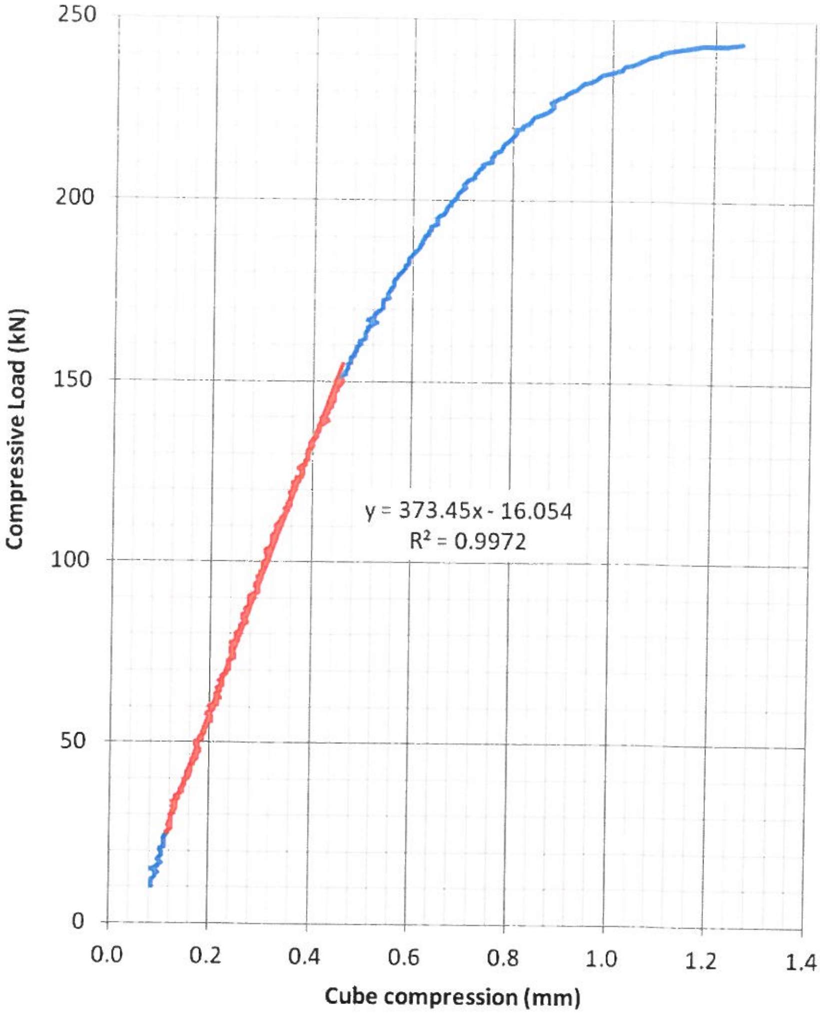

Figure B.1: Load-stroke relationship for compression test on cube sample no. 1.

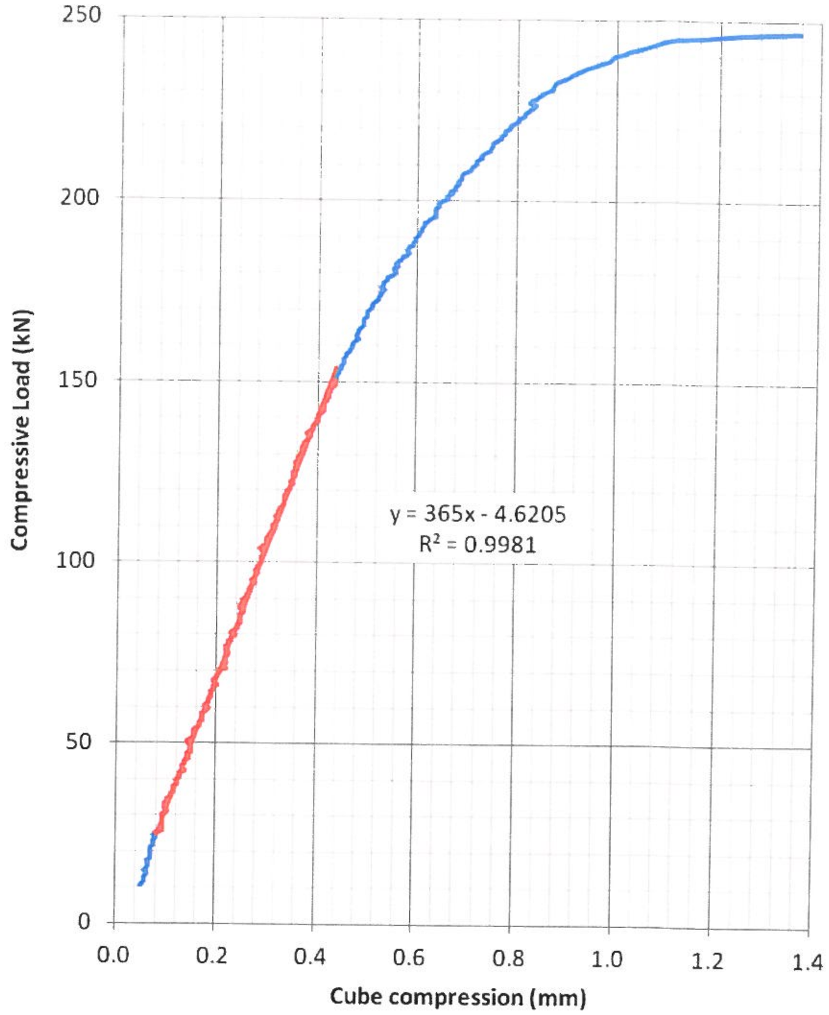

Figure B.2: Load-stroke relationship for compression test on cube sample no. 2.

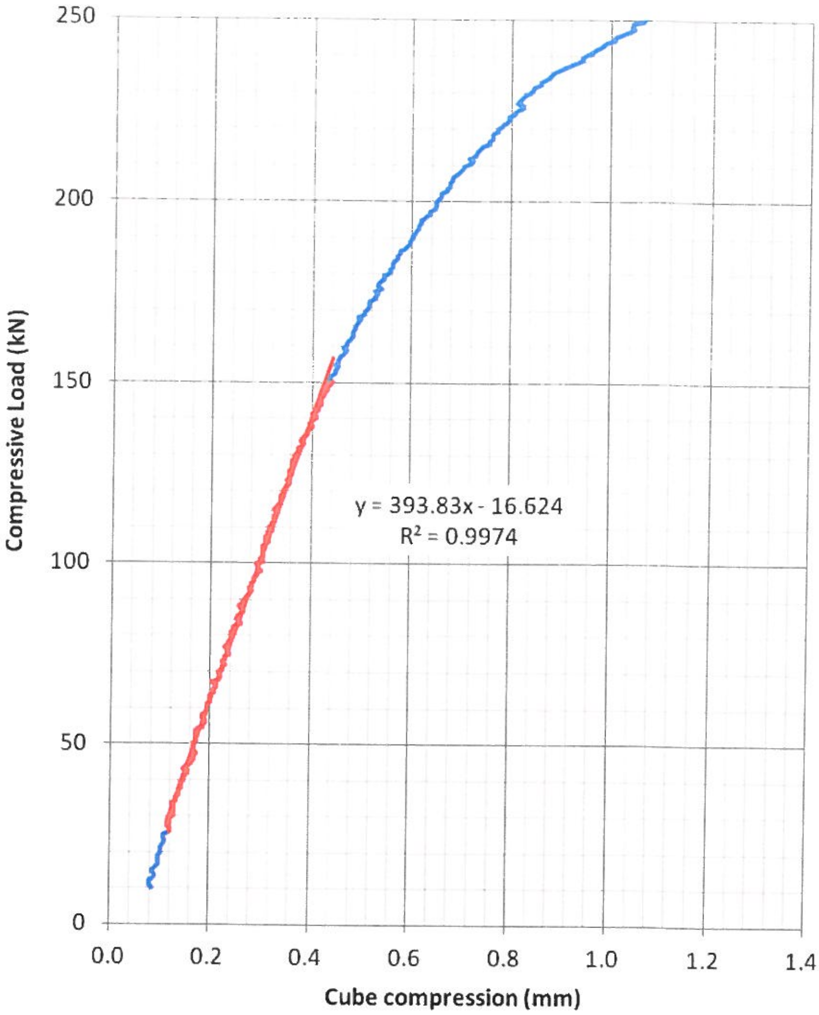

Figure B.3: Load-stroke relationship for compression test on cube sample no. 3.

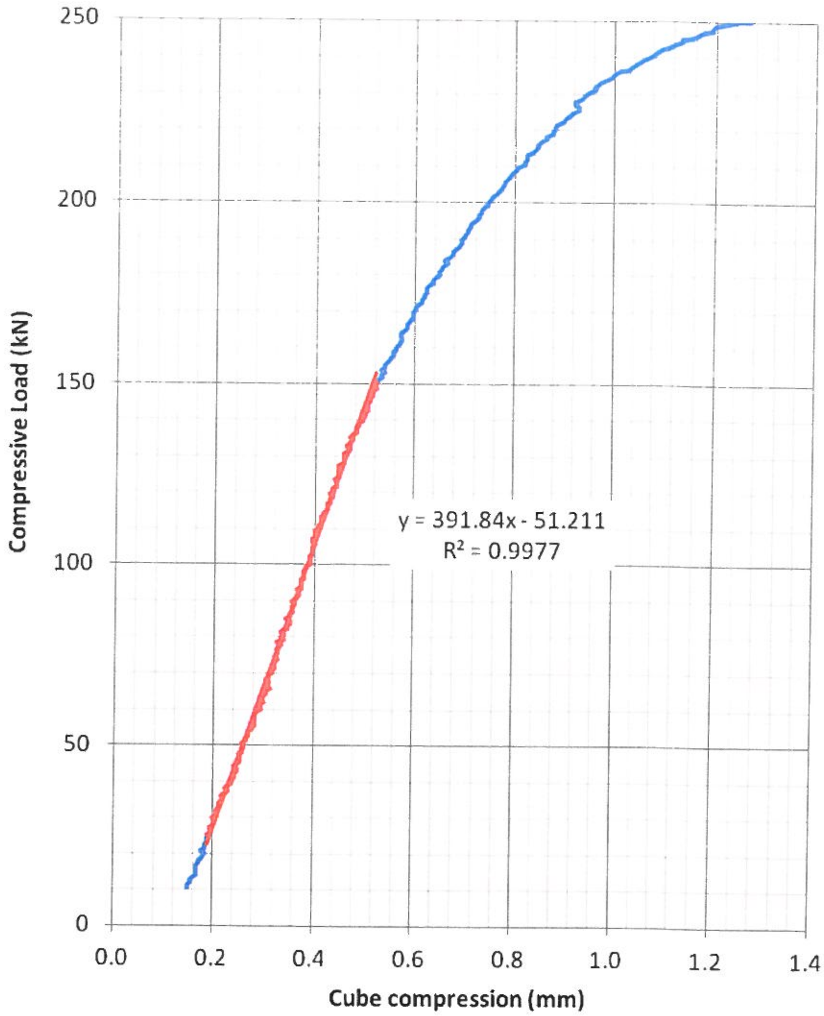

Figure B.4: Load-stroke relationship for compression test on cube sample no. 4.

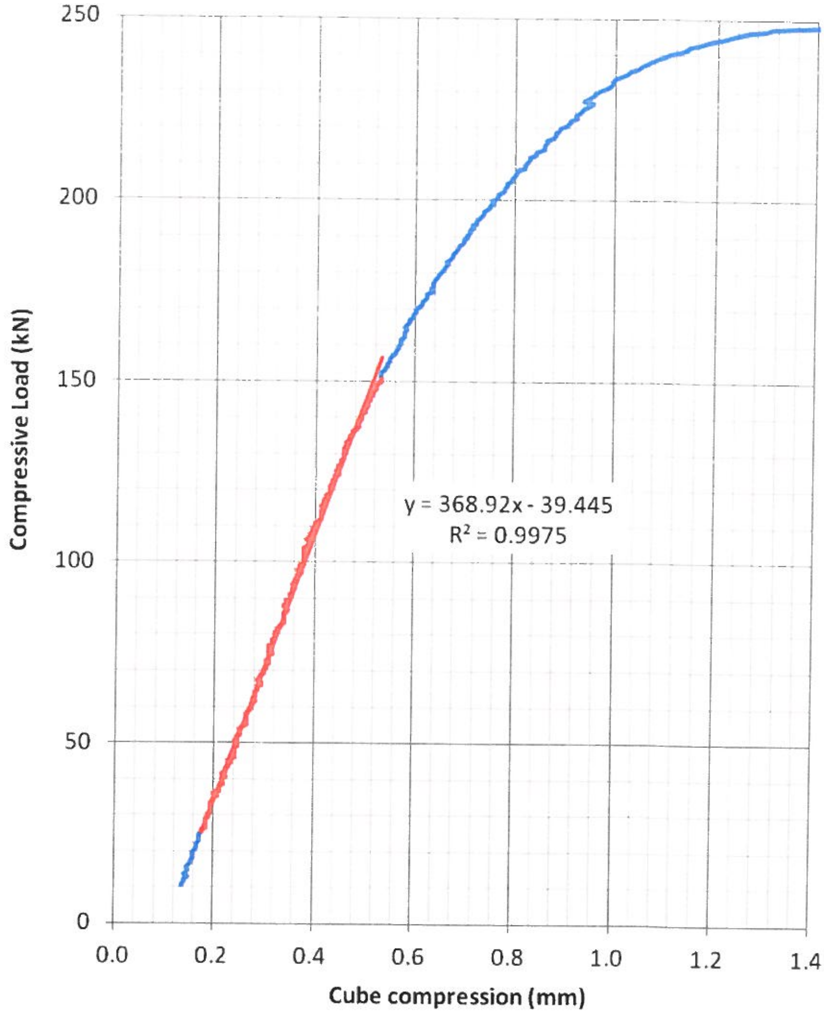

Figure B.5: Load-stroke relationship for compression test on cube sample no. 5.

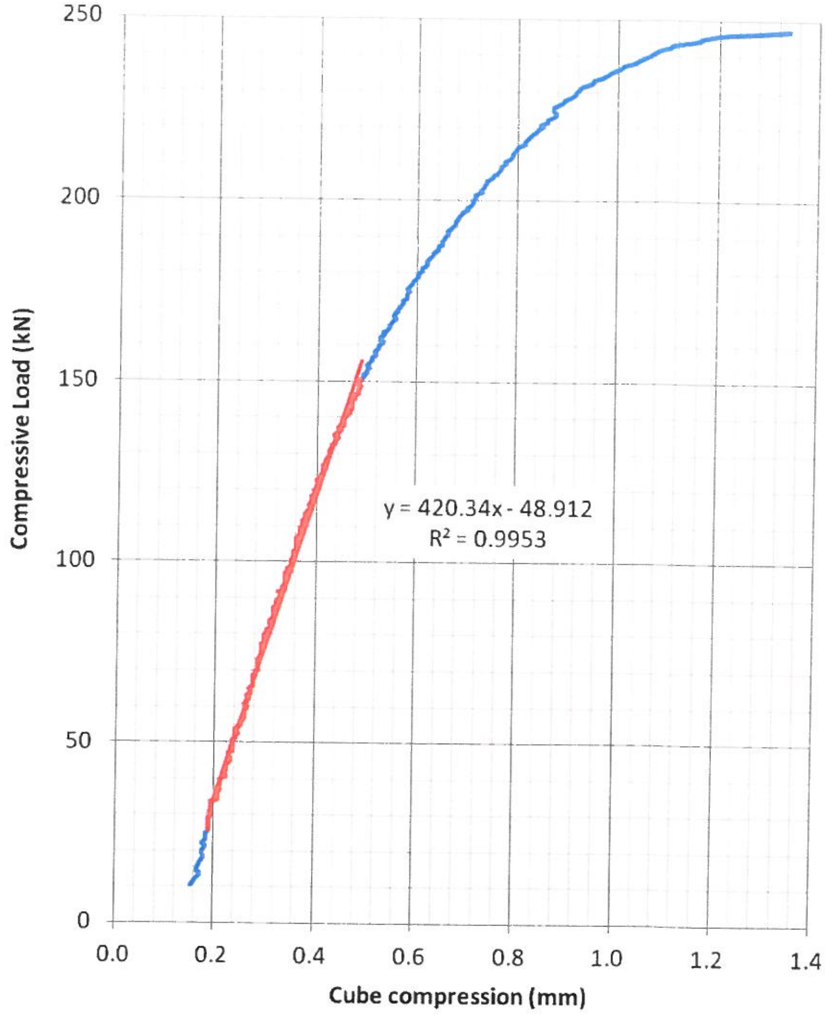

Figure B.6: Load-stroke relationship for compression test on cube sample no. 6.