TENSION AND COMPRESSION TESTS

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Engineering and Architectural Design

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Abstract

The aim of this experiment was to examine and compare the performances of some of the most commonly-used engineering materials by carrying out tension and compression tests. Mild steel, aluminum and two specimens of timber (one with grain parallel to the load and the other with grain perpendicular to the load) were tested in the tension experiment. Two specimens of concrete (one is cylindrical and the other is cubic) and two specimens of timber (one with grain parallel to the load and the other with grain perpendicular to the load) were tested in the compression experiment. Universal Testing Machine was utilized during the whole tests.

Several conclusions can be generated from the lab result. In the tension test, mild steel is more ductile and stronger, and timber specimen with grain parralel to load has the stress about 20 times as timber with grain perpendicular to load. In the compression test, timber with grain perpendicular to load is more ductile and less strong, and the strength of cubic concrete is about 1.78 times as cylindrical concrete. There exists deviation in the lab data generated and the real value, and the reasons are analyzed in the discussion section of this essay.

1. Introduction

In this experiment, several common building materials including aluminum, steel, concrete and timber were tested and analyzed in their tension and compression performances. Each specimen would be loaded to its plastic deformation range, and then fail, so that the data of maximum load, failure load, elastic limit, and maximum stress could be obtained and calculated.

2. Experimental Equipment and Method

2.1 Apparatus

A Universal Testing Machine, which was operated by a lab technician, was utilized to carry out the tension and compression experiments.

Fig 1 shows the experimental apparatus used in the tests. The universal testing machine is designed to determine the stress-strain curves of thin materials such as polymers and particularly metallic films deposited onto polymeric substrates [1]. It produces small deformations at low velocities and consequently, high resolution. Elastic modulus, yield point, and maximum stress can all be obtained from the tested samples [1]. An important feature of this device is the simplicity to exchange components according to the user requirements: the low cost, low machine compliance and the high resolution obtained [1].

(Fig 1. The Universal Testing machine used in the experiments.)

2.2 Experimental Methods and procedures

This experiment includes tension and compression test. The procedures of the tension tests are described as follow:

Step 1. The dimensions of the specimens were measured before the test, including the length and the cross-sectional areas.

Step 2. The technician located the specimens in the tension test machines. Mild steel, aluminum, timber with grain parallel to the load and timber with gain perpendicular to the load were consecutively put in the machines.

Step 3. The specimens were tensed and loaded into the plastic deformation range. They then cracked at the failure load. The load and deformation were measured and recorded in the computer throughout the process.

Step 4. Broken specimens were removed from the machine. Mild steel and aluminium were measured in the reduction in cross-sectional area and the increase in length. Changes in these dimensions were nevertheless hard to measure for timbers.

Step 5. The behaviours and appearance of the failed specimens were recorded and sketched. Stress-strain lines were plotted according to the load-displacement lines, and the characteristics of each specimen were analyzed, compared and discussed in the report.

The procedures of the compression tests are described as follow:

Step 1. The measurements of the specimens were conducted like the tension test.

Step 2. The technician located the specimens in the compression test machines. Two specimens of concrete (one is cylindrical and the other is cubic) and two specimens of timber (one with grain parallel to the load and the other with grain perpendicular to the load) were put in the machines consecutively.

Step 3. The specimens were compressed and loaded to failure. The load and deformation were measured and recorded in the computer throughout the process.

Step 4. Broken specimens were removed from the machine. The behaviours and appearance of the failed specimens were recorded and sketched. Stress-strain lines were plotted according to the load-displacement lines, and the characteristics of each specimen were analyzed, compared and discussed in the report.

3. Measurements and results

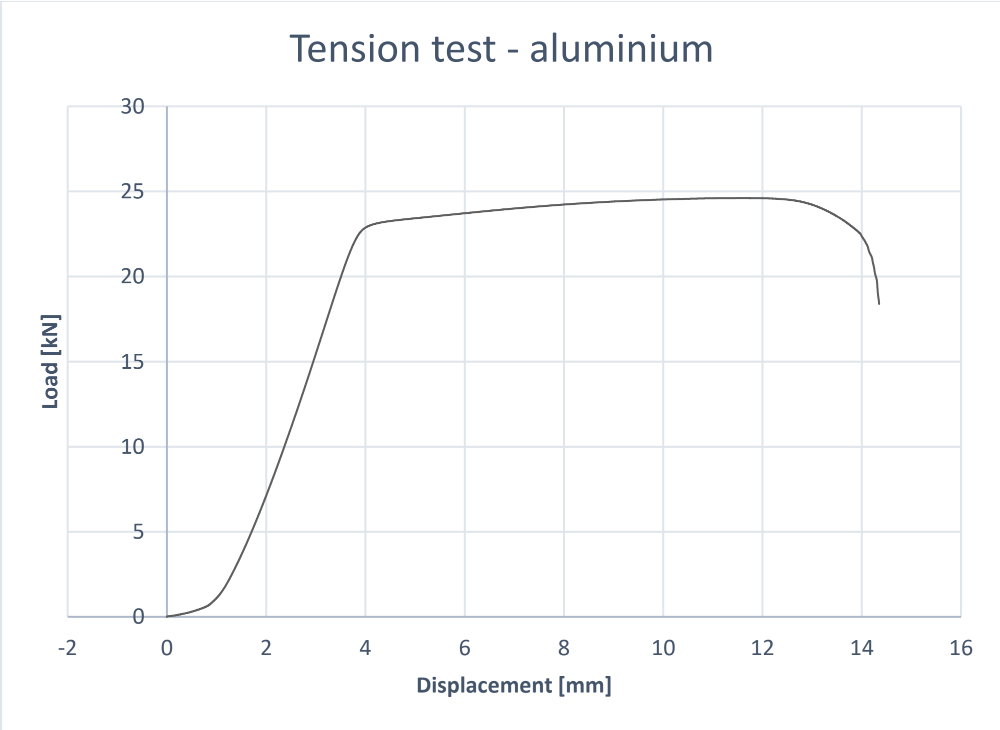
3.1 Tension test

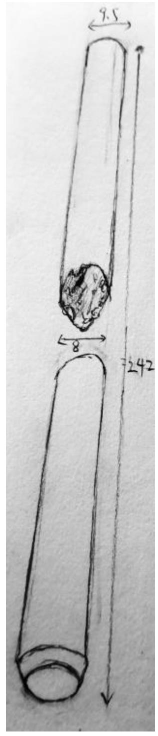
Measured value	Unit	MILD STEEL	ALUMINUM	TIMBER	
				Load // to grain	Load ⊥ to grain
Pre-testing dimensions	mm	8.9(diameter)	9.1 (diameter)	9.8*42.6	8.0*42.6
Pre-testing X-sectional area	mm^2	62.2	65.0	417.5	340.8
Load at elastic limit	kN	25.89	23.04	15.45	0.73
Maximum load	kN	36.616	24.610	19.530	0.767
Failure load	kN	26.033	18.388	4.530	0.735
Reduction in area	%	N/A	N/A		
Area of failure	mm^2	N/A	N/A		
Elongation at failure	%	43.4	15.0		

(Table 1. Measured values of the tension test)

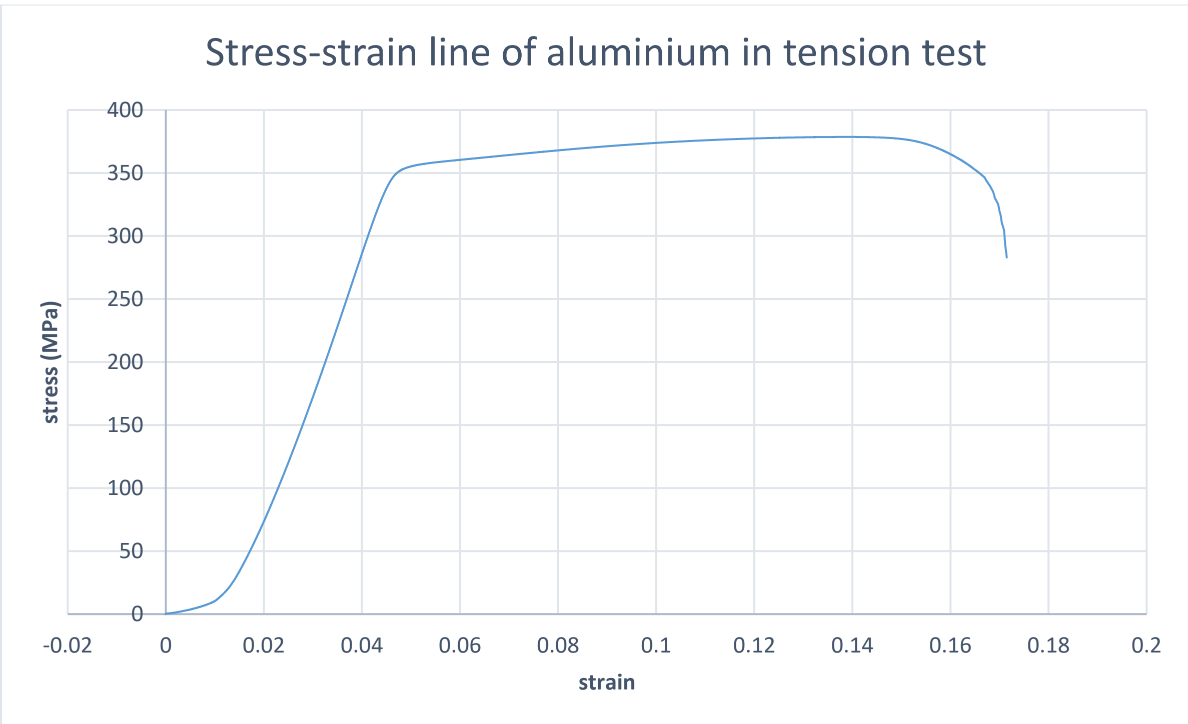
Property	Unit	MILD STEEL	ALUMINUM	TIMBER	
				Load // to grain	Load ⊥ to grain
Elastic limit (or yield) stress	MPa	416.17	354.24	37.01	2.14
Maximum stress	MPa	588.68	378.62	46.78	2.25
Failure stress	MPa	418.54	282.89	10.86	2.16
True failure stress	MPa	N/A	N/A		

(Table 2. Analyzed values of the tension test)

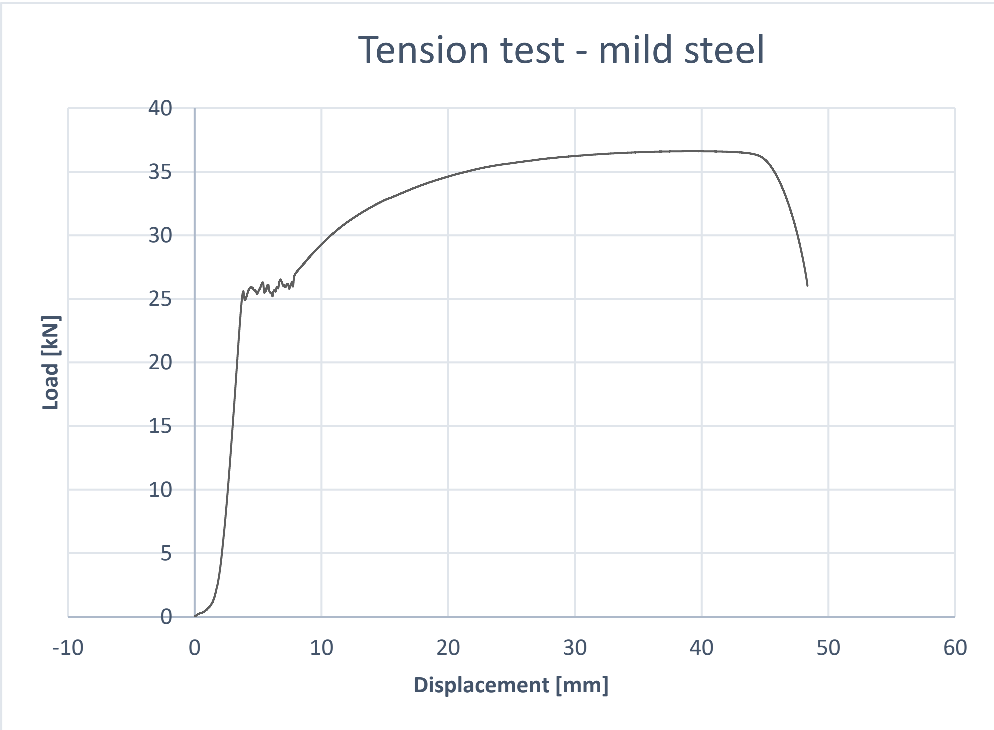


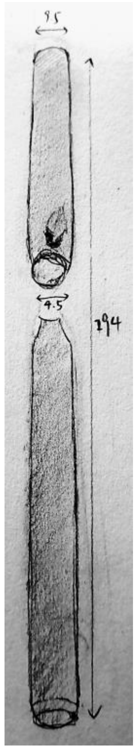


(Plot 1a & Sketch 1. Load-displacement graph for aluminium in tension test & Sketch of the crack detail of the specimen)

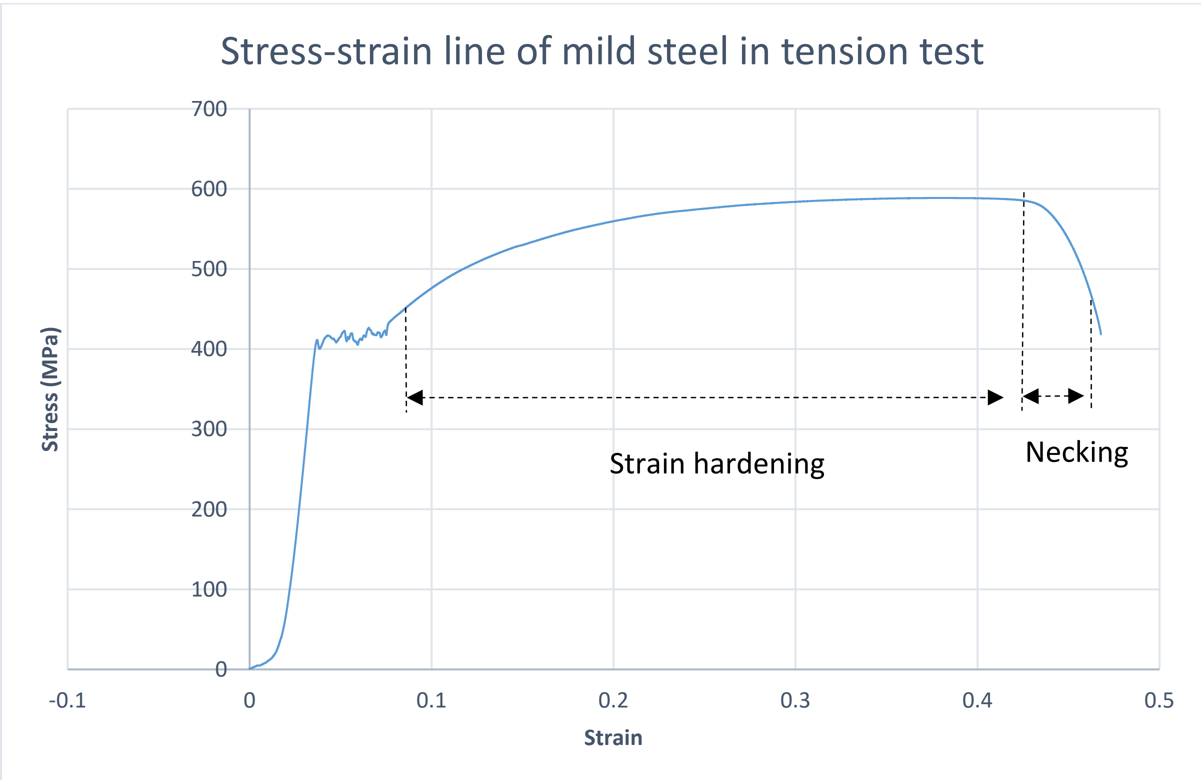


(Plot 1b. Stress-strain graph for aluminium in tension test)

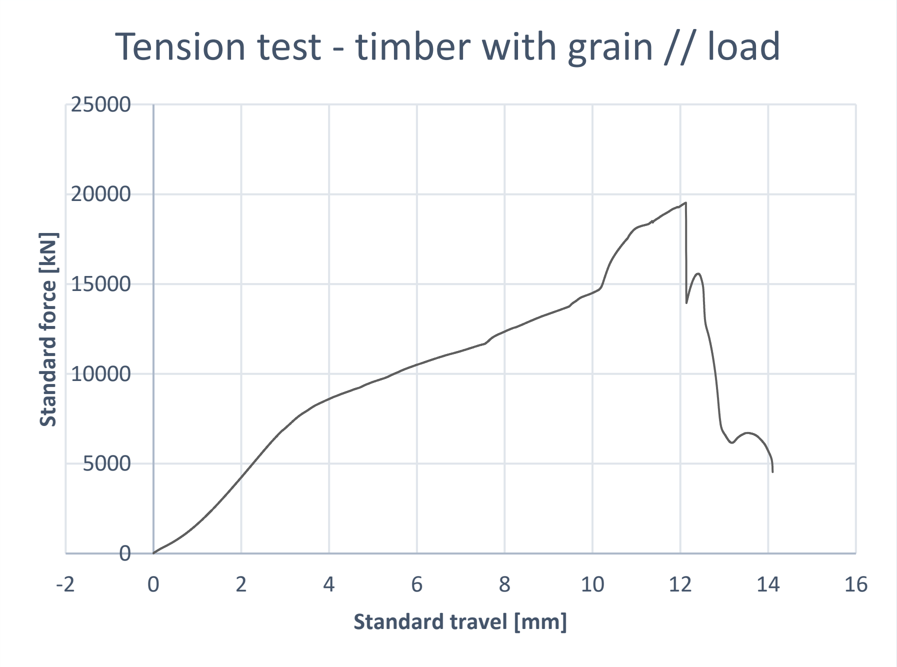


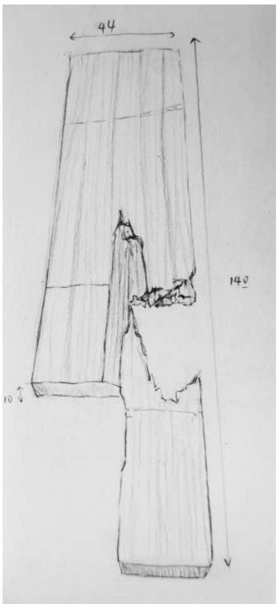


(Plot 2a & Sketch 2. Load-displacement graph for mild steel in tension test & Sketch of the crack detail of the specimen)

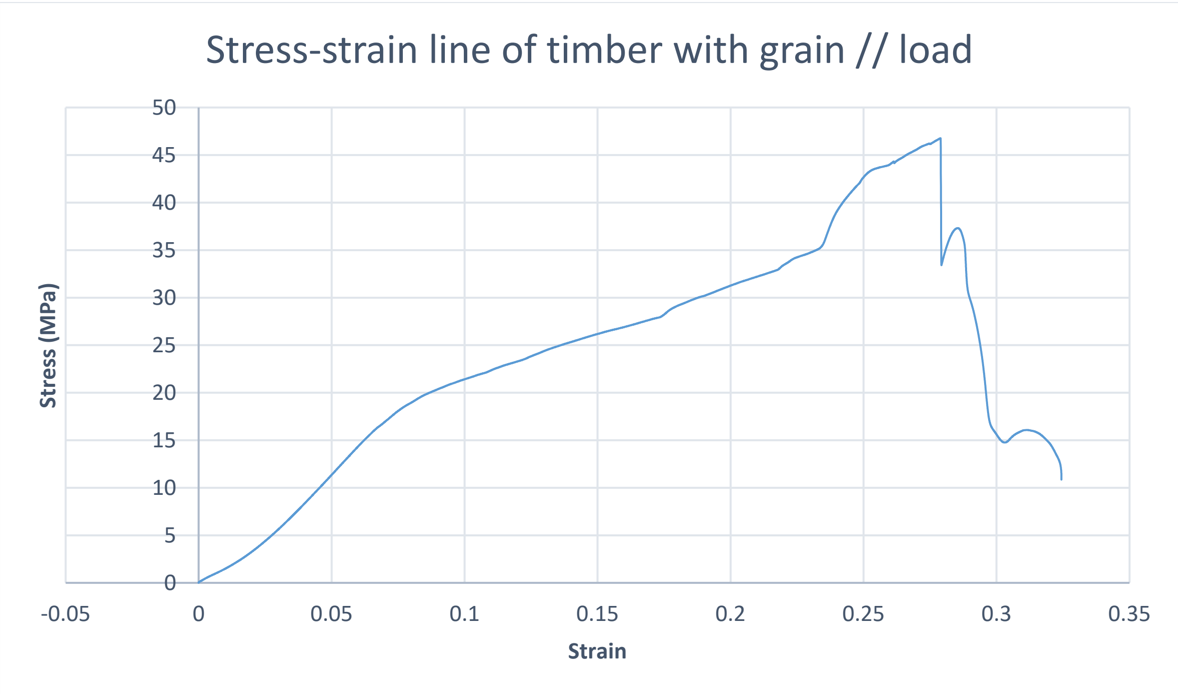


(Plot 2b. Stress-strain graph for mild steel in tension test)

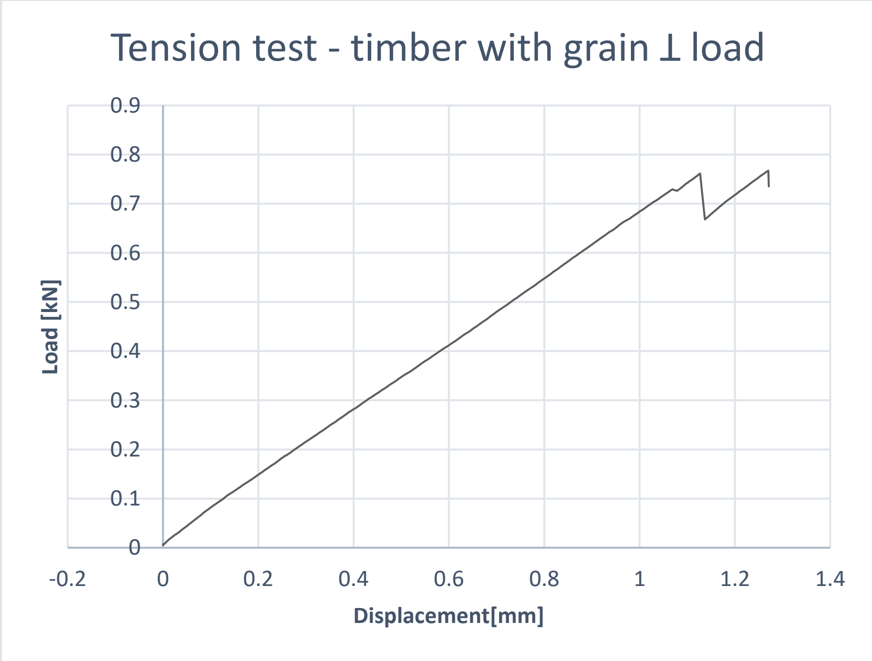


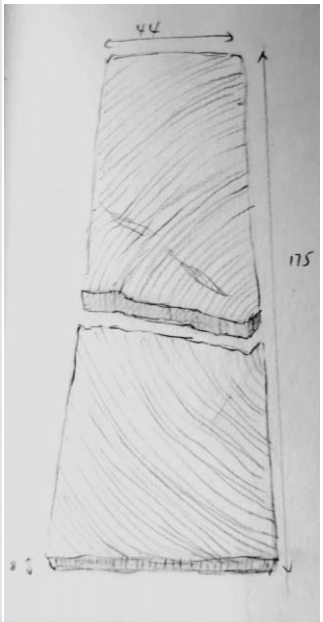


(Plot 3a & Sketch 3. Load-displacement graph for timber with grain parallel to load in tension test & Sketch of the crack detail of the specimen)

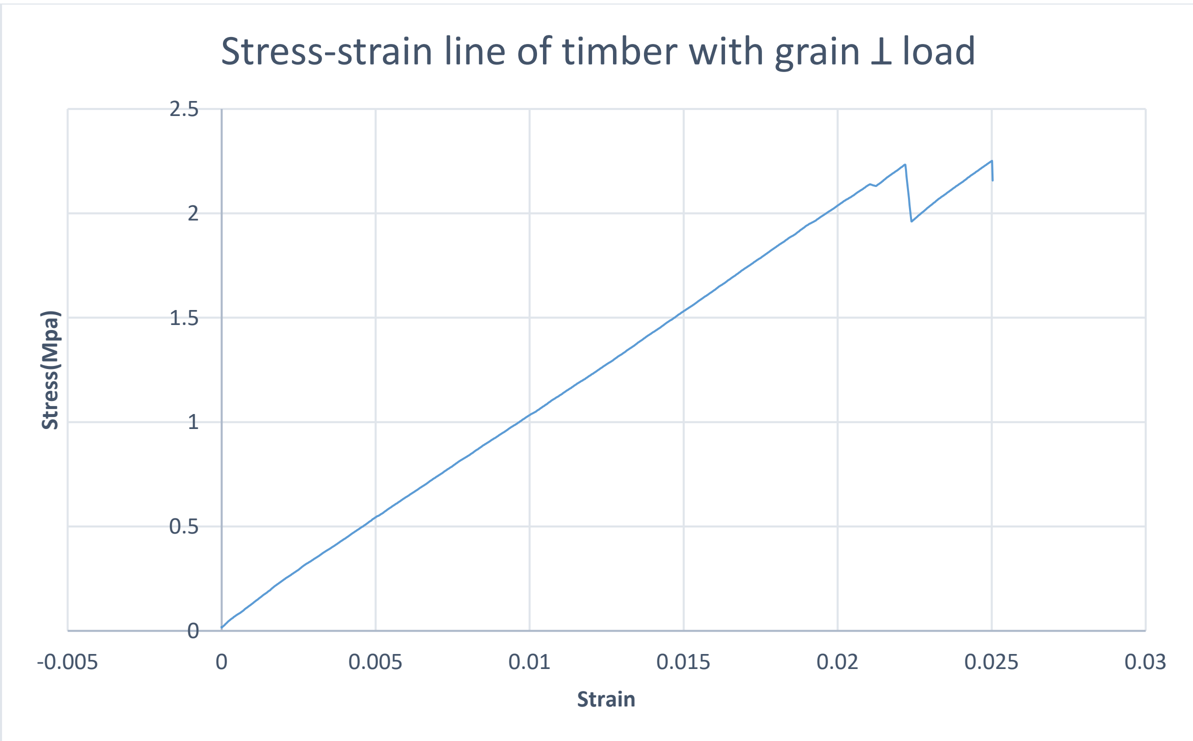


(Plot 3b. Stress-strain graph for timber with grain parallel to load in tension test)





(Plot 4a & Sketch 4. Load-displacement graph for timber with grain perpendicular to load in tension test & Sketch of the crack detail of the specimen)



(Plot 4b. Stress-strain graph for timber with grain perpendicular to load in tension test)

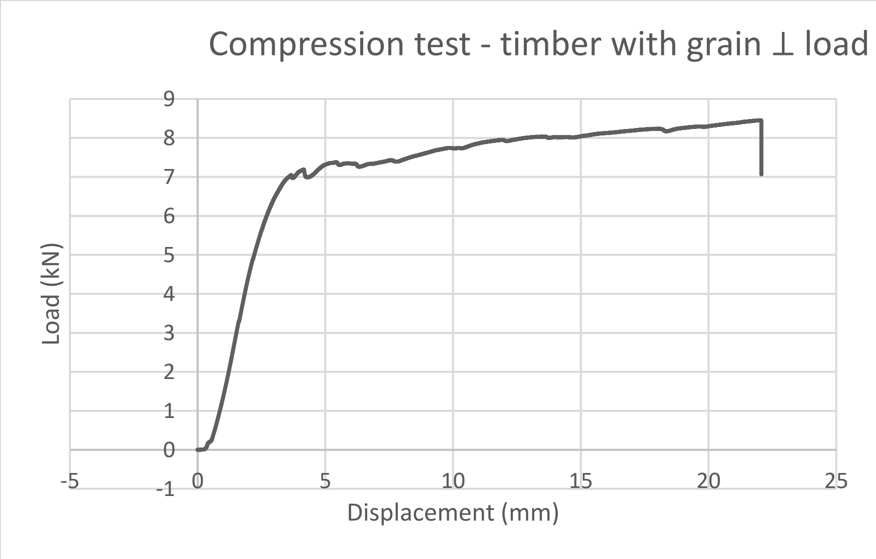
3.2 Compression test

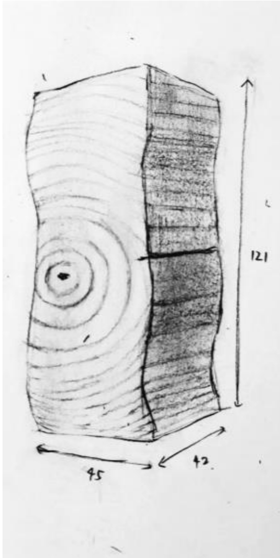
Measured value	Unit	CONCRETE		TIMBER	
		Cylinder	**Cube**	**Load // to grain**	**Load ⊥ to grain**
Pre-testing dimensions	mm	100(diameter) *200	100	42*42*120	45*42*142
Pre-testing X-sectional area	mm^2	7853.98	10000	1764	1890
Maximum load	kN	246.4	570.2	84.515	83.84
Failure load (if any)	kN	246.4	570.2	N/A	N/A

(Table 3. Measured values in the compression test)

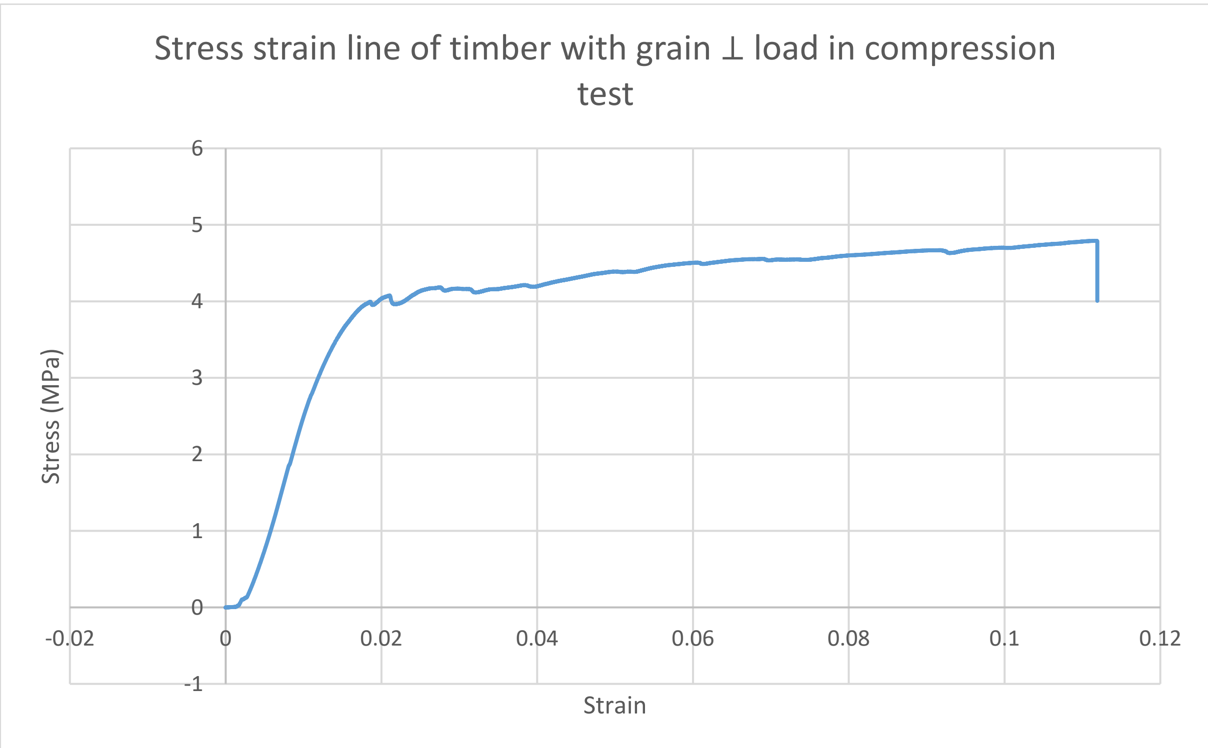
Property	Unit	CONCRETE		TIMBER	
		Cylinder	**Cylinder**	**Load // to grain**	**Load ⊥ to grain**
Stress at first deformation	MPa	N/A	N/A	40.06	N/A
Maximum stress	MPa	31.37	57.02	4.79	44.91
Failure stress (if any)	MPa	31.37	57.02	N/A	N/A

(Table 4. Analyzed values of the compression test)

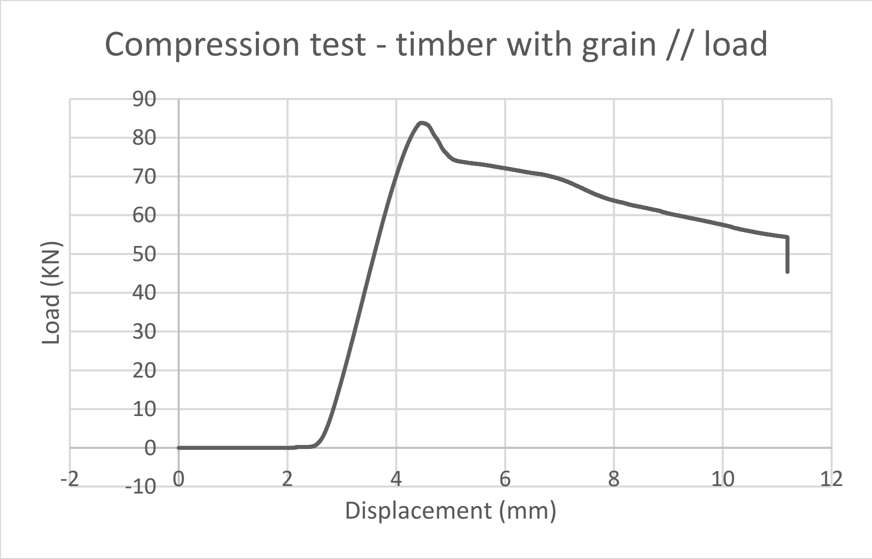




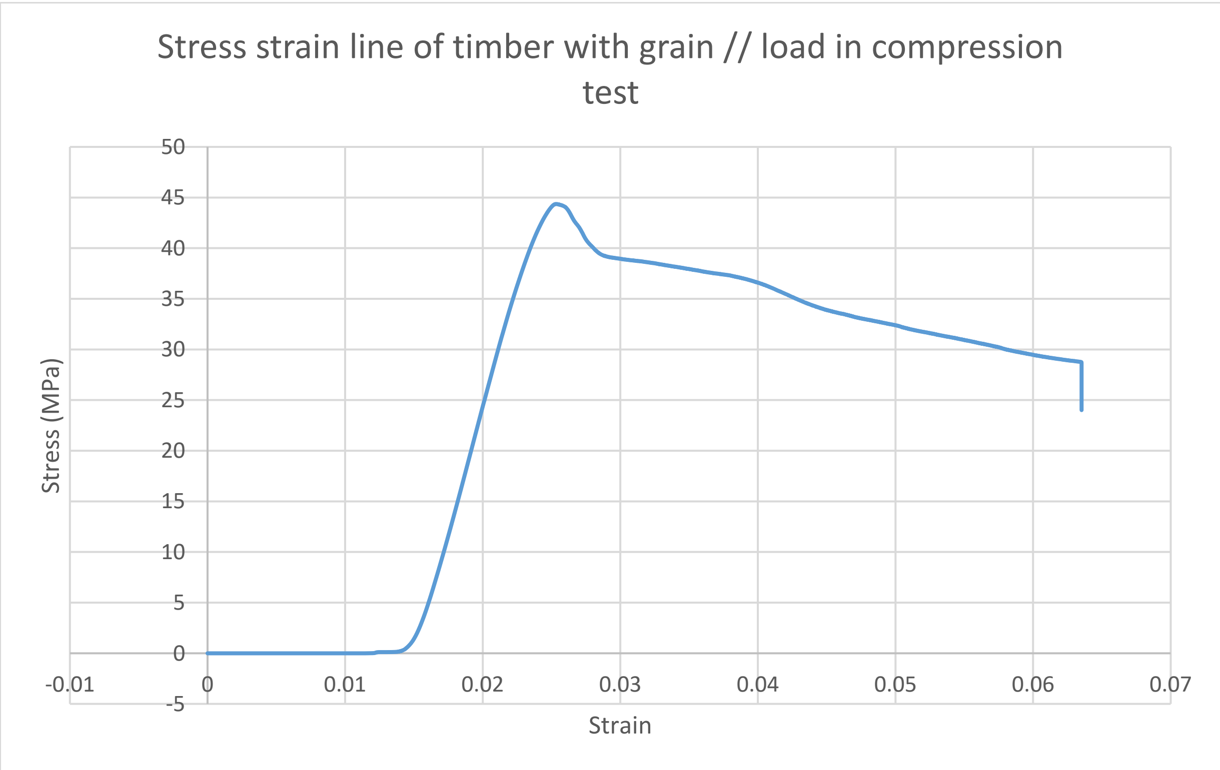
(Plot 5a & Sketch 5. Load-displacement graph for timber with grain perpendicular to load in compression test & Sketch of the crack detail of the specimen)



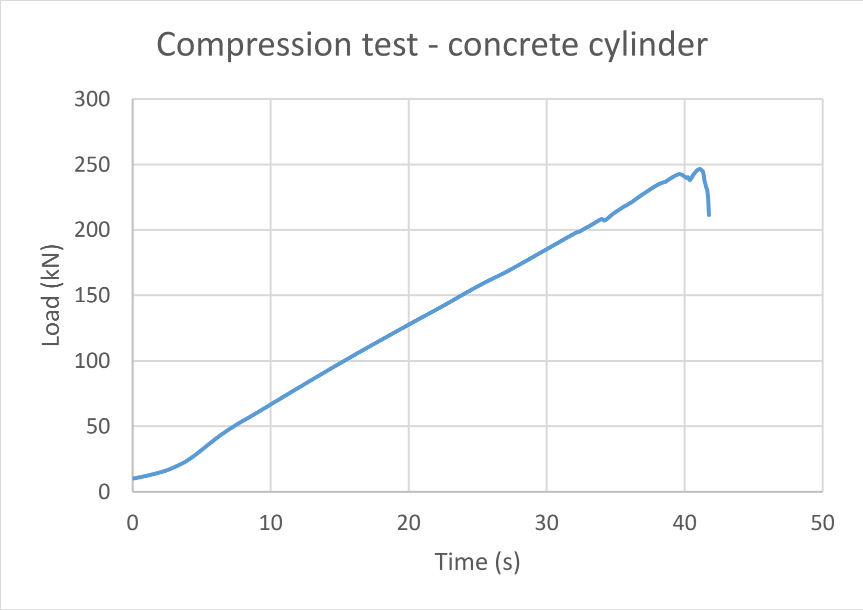
(Plot 5b. Stress strain graph for timber with grain perpendicular to load in compression test)

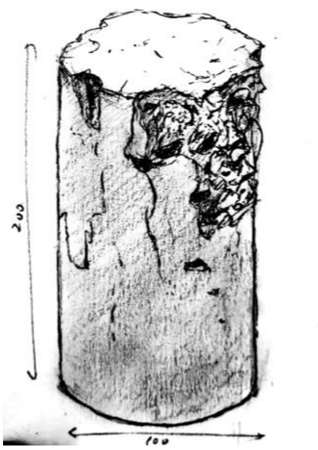


(Plot 6a & Sketch 6. Load-displacement graph for timber with grain parallel to load in compression test & Sketch of the crack detail of the specimen)

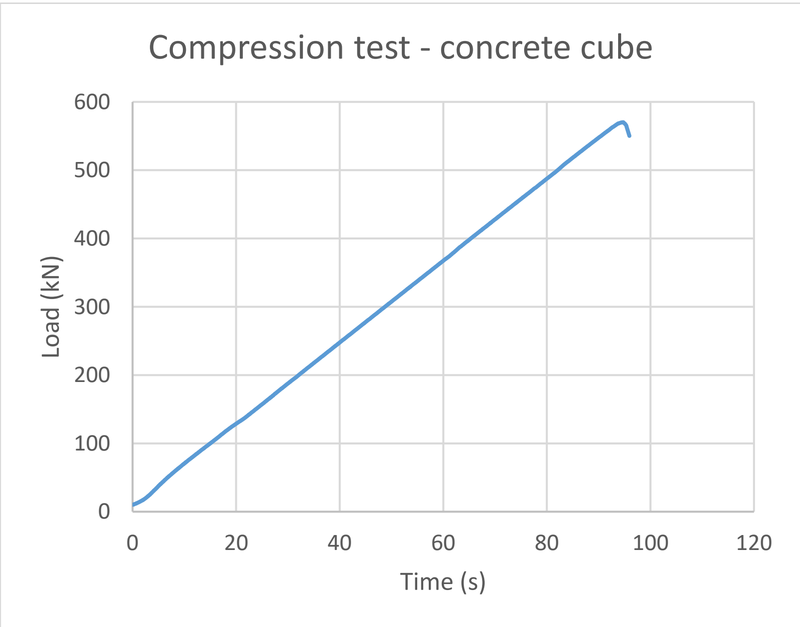


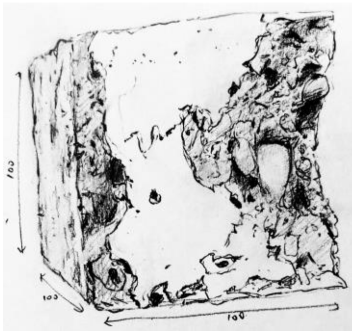
(Plot 6b. Stress-strain graph for timber with grain parallel to load in compression test)





(Plot 7a & Sketch 7. Load-time graph for concrete cylinder in compression test & Sketch of the crack detail of the specimen)

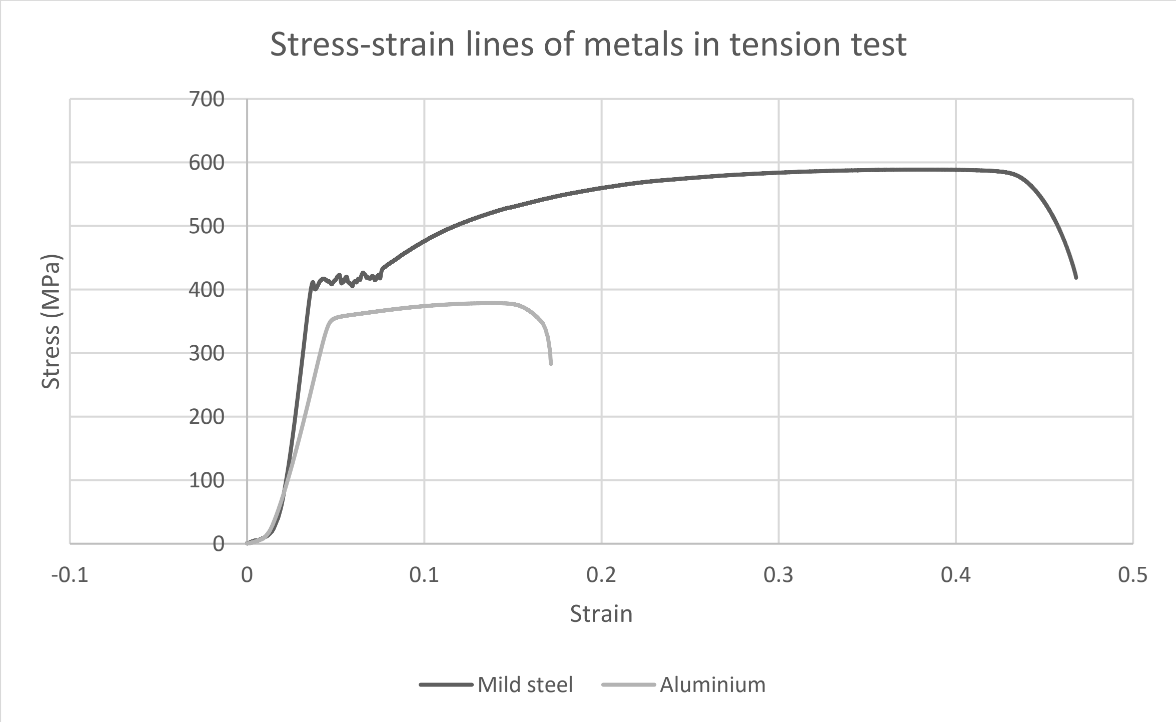




(Plot 8a & Sketch 8. Load-time graph for concrete cube in compression test & Sketch of the crack detail of the specimen)

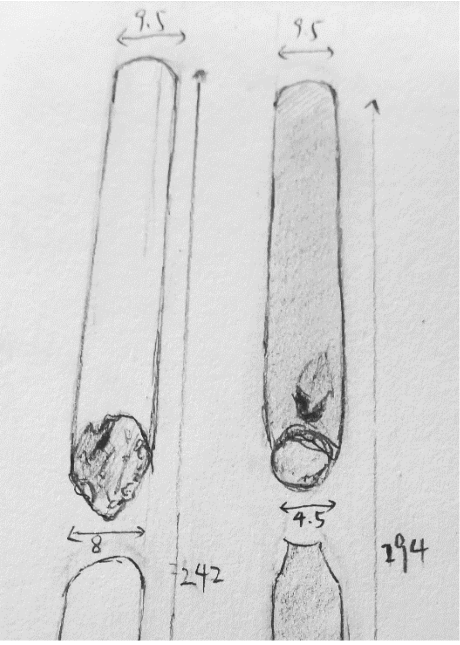
4. Conclusions and discussions

To compare and analyze the behaviours of different materials in the same test, several pairs of curves are put together in one graph.



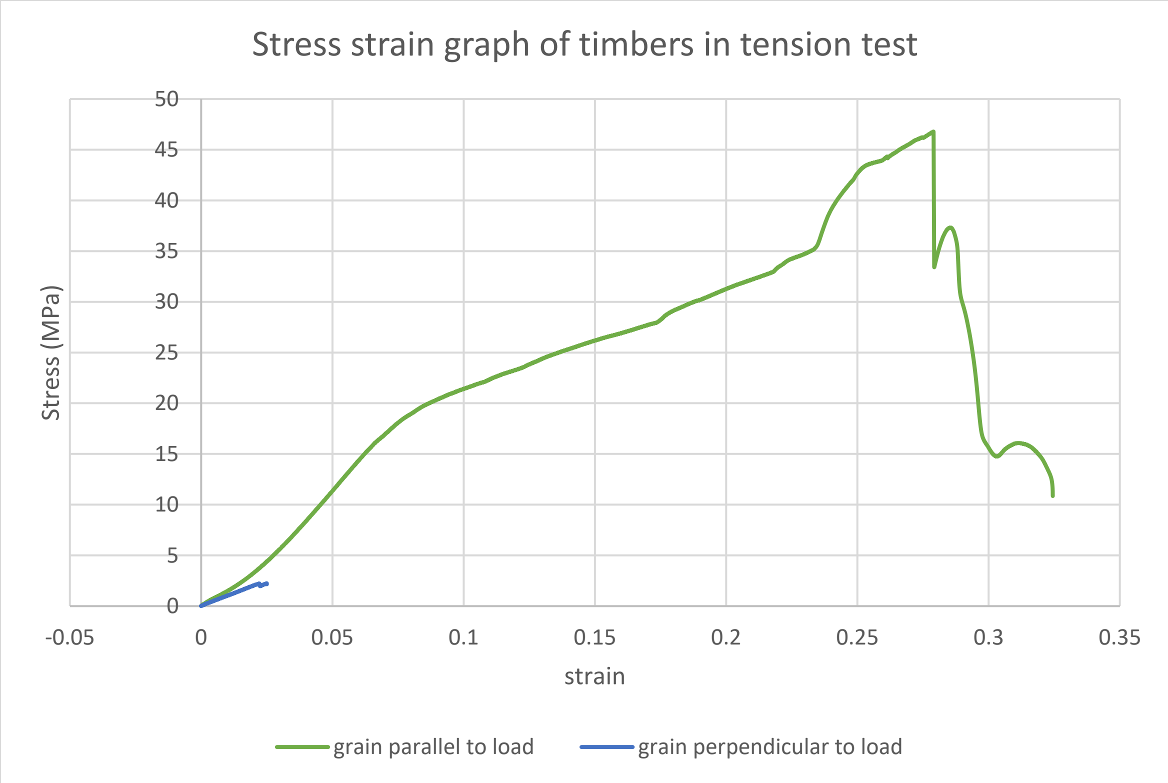
(Plot 9. Stress strain lines of metals in tension test.)

It can be observed from Plot 9 that in the tension test, mild steel is more ductile and stronger. Several other characters of materials can also be seen from the graph. First, aluminium has a far less range of hardening and necking compared to mild steel, which leads to the bigger sectional area of the cracking surface (See Sketch 9). Second, mild steel undergoes a period of fluctuation in its stress before the yield point, while the stress-strain line of aluminium is generally smooth and continuous.



(Sketch 9. Comparison between the cracking surface of aluminium and mild steel. Left: aluminium & right: mild steel)

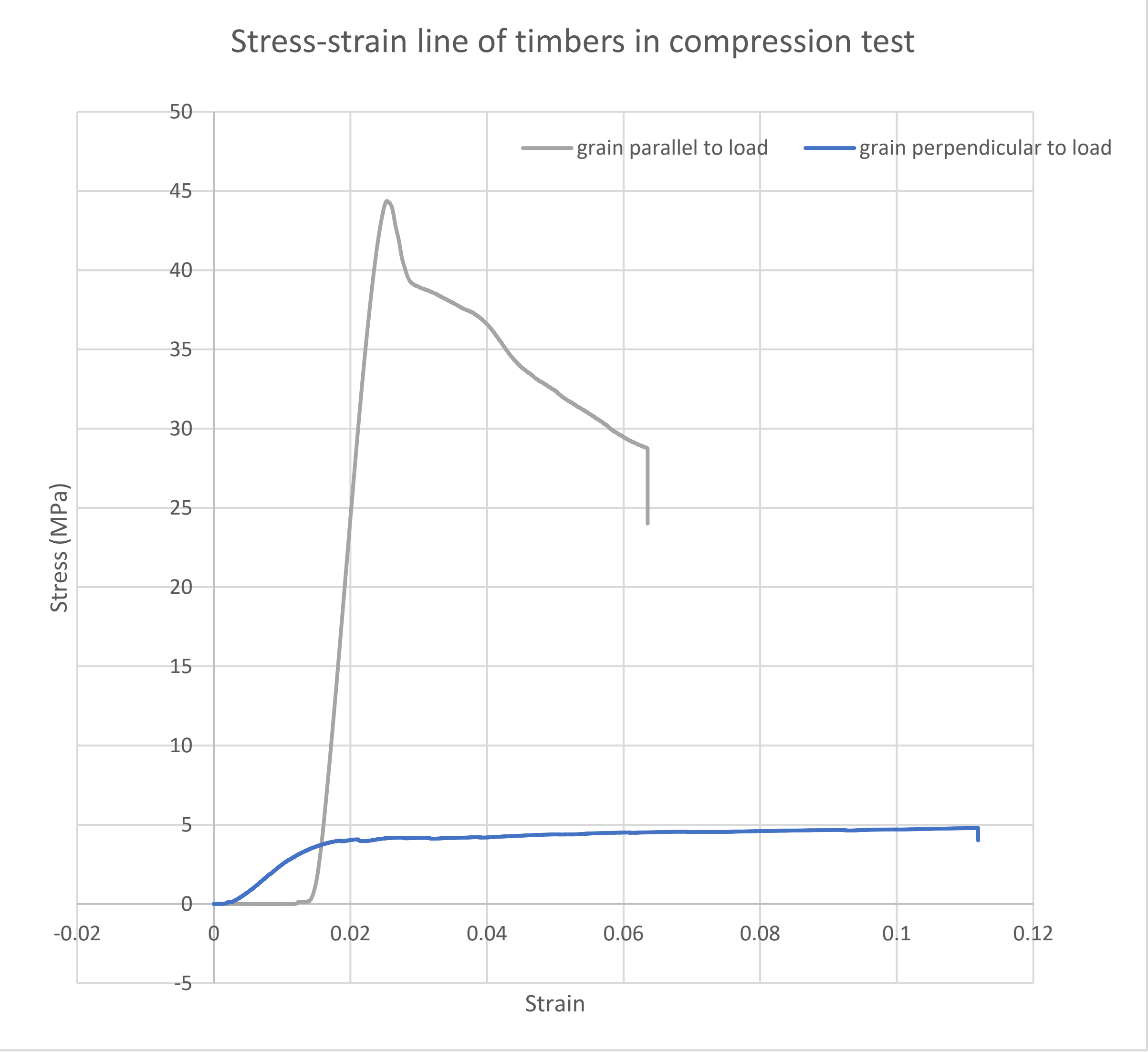
The pure aluminium in this experiment doesn’t have a high tensile strength [2]. However, by adding alloying elements like manganese, silicon, copper and magnesium the strength properties of aluminium can be greatly increased and produce an alloy with properties tailored to particular applications [2].



(Plot 10. Timbers with grain parallel to load and perpendicular to load in tension test)

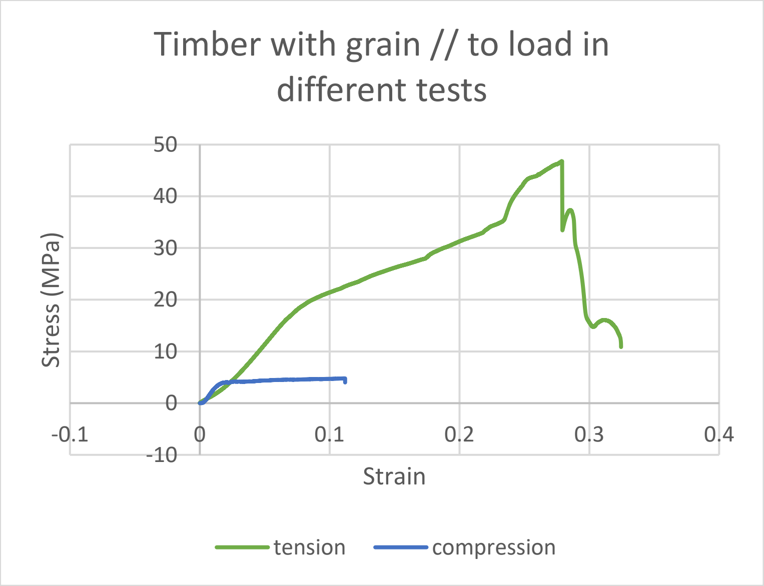
According to Plot 10, timber specimen with grain parralel to load can resist much greater, about 20 times, tension force compared to timber with grain perpendicular to load. This result is compliant with the data 'tensile strength in the direction of the grain is usually 10-20 times more than its strength perpendicular to the grain' [3].

Many other conditions also affect the strength of wood apart from the direction of grain, such as the density of the wood, temperature and so forth [3]. For example, the tensile strength of the spring wood in a pine is only 1/6 of that of summer wood, and the compression strength of air-dry wood is about half of the corresponding tensile strength [3].

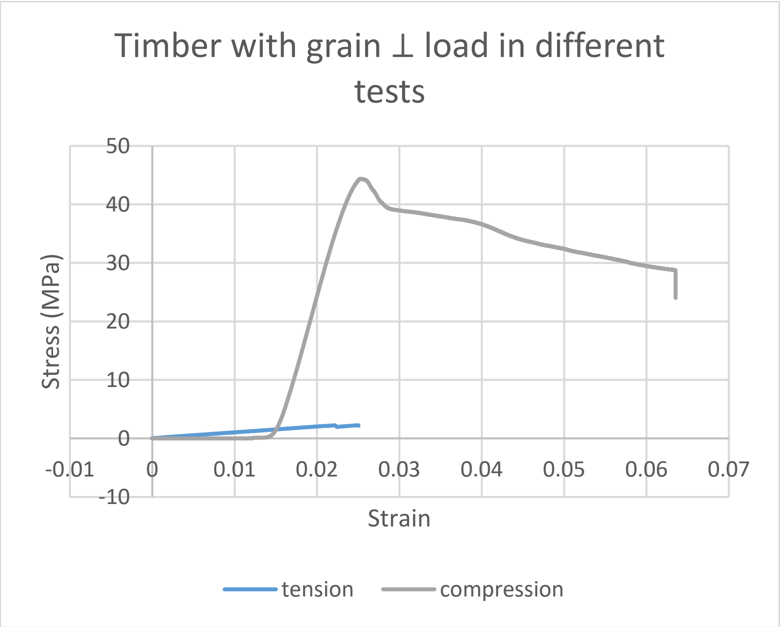


(Plot 11. Stress strain lines of timbers in compression test)

Timber with grain perpendicular to load is more ductile and less strong according to the graph. The curve of timber with grain parallel to load in this graph has a range where stress stays at 0. This is maybe due to the delay in operation during the experiment.

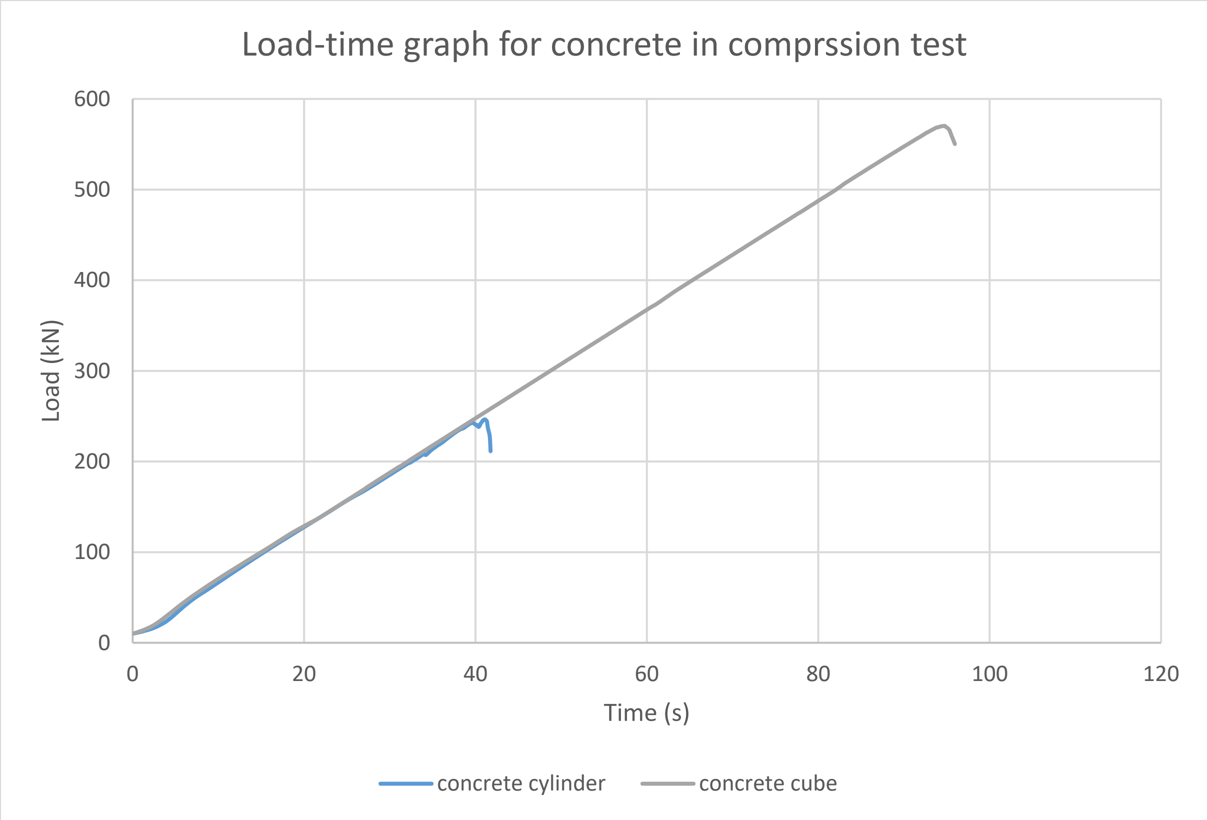


(Plot 12. The tensile and compressive behaviours of timber with grain parallel to load)



(Plot 13. The tensile and compressive behaviours of timber with grain perpendicular to load)

Timber behaves greatly differently under tension and compression. In Plot 12 timber with grain parallel to load is extremely ductile under tension, yet relatively brittle under compression. In Plot 13, timber with grain perpendicular to load is much stronger and more ductile under compression than in tension.



(Plot 12. Load- time graph of concrete cylinder and concrete cube)

Plot 12 is the demonstration of how cylindrical and cubic concrete behave under compression. According to the graph, two specimens were applied to the same load at the same rate, and cylindrical concrete fractures at 40s and cubic concrete fractures at around 95s. Due to the brittle quality of concrete, the data of displacement are hard to gain, and thus the stress-strain line for concrete cannot be generated. However, the strength of the specimens can be calculated by $\frac{The\ maximum\ load}{sectional\ area}$:

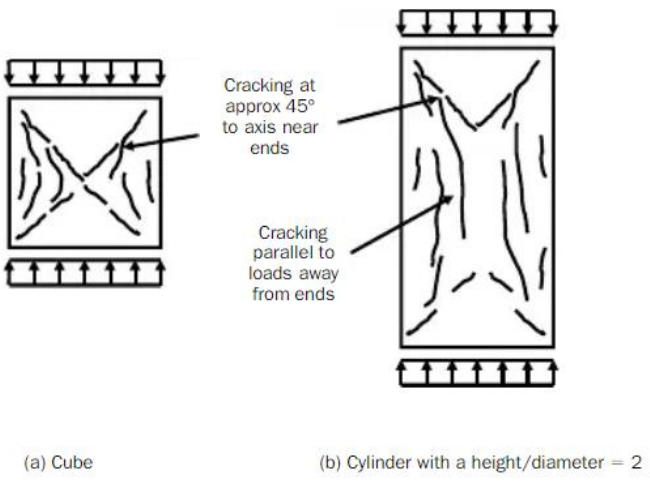
$$\delta_{cylinder} = \frac{252 \times 1000}{\pi \times 50^2 \times 10^{-6}} = 3.2 \times 10^7 Pa$$

$$\delta_{cube} = \frac{568 \times 1000}{100^2 \times 10^{-6}} = 5.7 \times 10^7 Pa$$

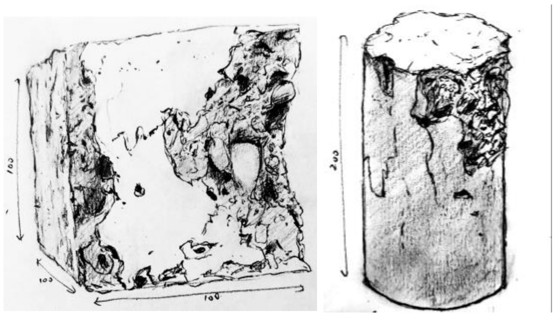
$$\frac{\delta_{cube}}{\delta_{cylinder}} = 1.78$$

According to the expression for conversion the strength of the cores in to equivalent cubes in BS 1881: part 120:1983[7] the strength of the cube is equal to 1.25 times the strength of the cylinder. The ratio generated in this experiment is 1.78, which bears a 30% difference. The reasons accounting for the divergence vary. According to Kurami [5]'s research, the factors that would affect the strength of concrete cylinder and cube are : (1) casting and curing procedure, (2) testing procedure, (3) size of specimen, (4) effect of size of particle, (5) effect of concrete strength level. The test may have been affected all these factors, such as the quality of aggregate (grading, surface texture, shape, strength and stiffness), the moisture condition of the concrete and the difference in casting procedures [5]. As a result there is no definite relation between the strengths of the specimens of these two shapes in reality [6].

The patterns of cracking also vary in cubic and cylindrical concrete. Fig. 2 shows the general cracking patterns of the concrete, which is generally compliant with the experimental result (Fig 3). The phenomenon that the concrete cracks from the corner is not uncommon. Concrete columns and walls always crack from the bottom and top corners, as shown in Fig 4.



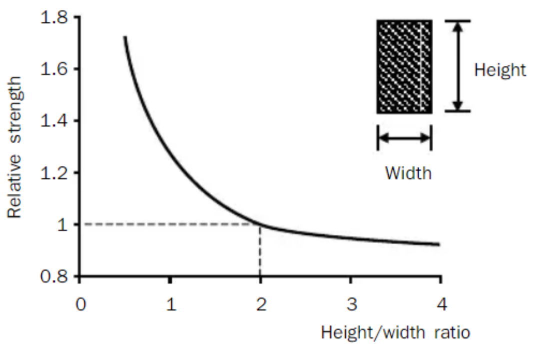
(Fig 2. Cracking patterns of concrete specimens in compression [4])



(Fig 3. Cracking patterns of cubic and cylindrical concrete in the test)

(Fig 4. Examples of cracks in concrete [8])

The strength of cylindrical concrete is also related to its ratio of height and width. The value of ratio is 2 in this experiment, and the greater the ratio is, the weaker the cylindrical concrete.



(Fig 5. The relationship between height/width ratio and the strength of concrete [4])

Reference:

[1] E. Huerta, J.E. Corona, and A.I. Oliva (2010), *Universal testing machine for mechanical properties of thin materials*, REVISTA MEXICANA DE FI´SICA, Vol. 56, Issue 4, pp. 317–322

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