Evaluation of the potential to machine grade reengineered timber using current machine settings

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Executive Summary

This project has clearly shown that strength grading machine settings for the current BS 5268 strength classes and the proposed grading machine settings for EN 338 strength classes, both for use on solid timber; do not effectively grade reengineered laminated timber.

The results obtained for the strength classes C16 and C24 were in the main indistinguishable from each other, which is a clear indication that the settings are inappropriate for the nature of the reengineered timber. The main problem is believed to be a separation of the measured strength, which is increased by the laminating process, and the stiffness of the original material that is not significantly changed by the laminating process. As the machine settings are based on this relationship for solid timber the separation of the two parameters results in a total inability for the machine settings to correctly identify the strength classes.

It is believed that the future of timber may well lie in the development of such reengineered products and that machine grading in one of the best ways of making such products accessible the market place. Therefore, to go forward with future work will need a greater drive from the UK sawmilling industry to identify products and take ownership of designs agreed within the industry on which a data base can be constructed for the derivation of suitable strength grading machine settings.

It should be stressed that the results in this report are for bending type machines and there is the possibility that strength grading machines that do not have a bending component as the indicating parameter may return more favourable result with laminated timber. However, strength grading machines that rely on density as a major component of the machine indicating parameter may be affected in a similar manner to bending type machines as the relationship between measured strength and density will be affected in a similar manner to the relationship for measured strength to stiffness.

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1 Introduction

The Partners in Innovation (PiI) project “Adding value to UK timber: Development and demonstration of glued laminated products” clearly demonstrated that there was potential for value adding to low value falling boards by glue lamination. That project demonstrated that from falling boards visually graded and attributed to a C18 strength class considerable improvements in the 5th percentile strength could be achieved. This naturally excited the sawmilling partners as it demonstrated that there was potential to value add to a low value product, one that is available in vast amounts.

To make most effective use of this technology and for the laminated products to be competitive against conventionally strength graded timber it was considered important that the laminated products should be machine graded and treated in exactly the same manner as normal timber, by attributing them to a strength class.

It is known that laminating timber can alter the basic relationship between certain properties, particularly strength with relation to stiffness and density. Laminated timber shows an enhancement of strength but there is no similar increase in stiffness or density. Though the 5th percentile value for strength increases the over all strength distribution is reduced along with a shift in the mean value for strength to the lower end of the distribution, there is less overall variability of strength within the sample. This can be shown diagrammatically in Figure 1.

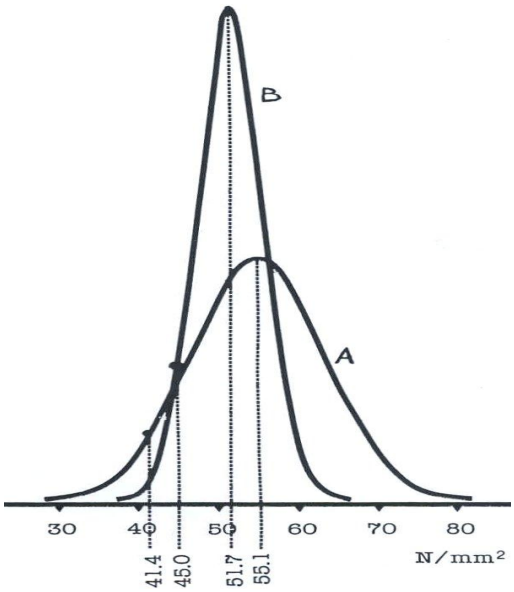

Figure1. Showing the distribution of strength between solid and re-engineered timber.

In Figure 1 (above), distribution A shows an idealised strength distribution for a sample of solid timber. This has a sample mean of 55.1 N/mm^2 and a 5th percentile value (the characteristic basis for structural strength) of 41.4 N/mm^2. The total range for the distribution is from just below 30 N/mm^2 to above 80 N/mm^2. When this is compared with distribution B for laminated timber of the same species, it can be seen

that the total range has been significantly reduced (just below 40 N/mm ^{2} to just below 70 N/mm^2). The 5th percentile value has increased from 41.4 N/mm ^{2} to 45 N/mm ^{2}. However, the mean of the distribution has been reduced from 55.1 N/mm ^{2} to 51.7 N/mm^2.

Therefore the effect of laminating timber is to significantly increase the usable structural strength (5th percentile value) and at the same time to reduce overall variability, but this will only apply to strength , stiffness and density will be predominately unaffected by the laminating process.

2 Description of the project

The aim of the project was to investigate if current machine settings resulted in acceptable grading results when applied to laminated timber. If laminated structural material is going to be competitive in the market it must compete on equal terms with solid structural material with regard to cost and the understanding of their structural properties. Machine strength grading of such material is the most readily identifiable route to achieve these ends.

This project was conceived to demonstrate to certain sawmilling partners where the current limitation might be in their desired intentions to produce this type of product and to evaluate the scale of any difficulties. The original intention was for the sawmilling partners to produce the majority of the laminated material but this was not possible due to the relatively long period of time taken for the sawmilling partners to be in a position to effectively produce the material, therefore, all the material was produced at BRE. It is only as the project is drawing to a close that the capability of one of the partners is such that they can produce laminated material from falling boards.

The laminated material has been produced from falling boards of Sitka spruce, for these trials the material has been ungraded. The PiI project “Adding value to UK timber: Development and demonstration of glued laminated products” showed that when such boards are visually strength graded they produced a yield between 60% to 90% of C18 material. Therefore, it is a reasonable to assume that the true 5^{th} percentile value for strength of the falling broads used in this study and before lamination is a little below that of a C18 strength class.

Three sizes of laminated material were made from falling boards supplied to BRE and these were:

- 60mm x 100mm – 80 specimens, in a three lamellae lay-up.
- 40mm x 150mm – 70 specimens, in a two lamellae lay-up.
- 40mm x 100mm – 100 specimens, in a two lamellae lay-up.

The total sample size was 250 specimens.

Three samples were used to evaluate the machine settings over a range of possible timber sizes, and to compare two and three lamellae lay-up arrangements to see if there was a difference in the laminated materials’ response to the machine settings.

Each sample was machined to improve tolerances and to bring them down to a suitable size for existing machine settings, the final dimensions were:

- 47mm x 100 mm
- 38mm x 150mm
- 38 mm x 97mm

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All the material was passed through the strength grading machine against the C16 / C24 setting for the appropriate section size and the grading data recorded for later comparison with the data from destructive testing to determine bending strength, stiffness and density. The grading data at the failure point together with the results of the testing were compared to the machine settings for both BS 5268 and EN 338 strength classes to determine how the samples performed.

3 Findings

3.1 General sample population statistics

Before carrying out the grading exercise the general data for each sample population were investigated. The 5th percentile value for strength, mean modulus of elasticity (MoE) and mean density were calculated, and these are displayed in Table 1

Table 1. Basic sample statistics – EN 338[1]

Sample	5th percentile value for strength N/mm^2	Mean MoE N/mm^2	Mean density kg/m^3
47mm x 100mm	21.79	9227	443
38mm x 150mm	26.24	9940	424
38mm x 97mm	21.82	9684	439

The basic statistics for all three samples are similar and they suggest there would be little material that would grade out against the C16 setting with most of the samples making the C24 strength class. This should be true for both EN 338 and BS 5268[2] settings if these settings were appropriate of the laminated material

The relationship between machine indicating parameter and measured strength for each sample has been determined, along with the coefficient of determination, these data is displayed in Figures 1 to 3 in Appendix A. Two of the samples (38mm x 97mm and 38mm x 150mm) have coefficients of determination below that required by BS EN 519[3] (R^2 equal to or greater than 0.47) for machine grading. This indicates that the material in these two samples will not grade appropriately, see Figures 1 to 3 in appendix A.

3.2 Sample 47mm x 100 mm – Three lamellae lay-up.

3.2.1 EN 338 settings

Set out below in Tables 2 to 4 are the results for the grading against the C16 / C24 strength class combination for the new EN 338 settings as determined using prEN 14081: Part 4[4].

Table 2. The results for the sample population selected by the C16 settings

Strength (5^{th} percentile) N/mm^2	Mean stiffness N/mm^2 (at 12% moisture content)	Density kg/m^3 (at 12% moisture content)
Data from test sample		
28.01	**9425.9**	**449**
Target values with permissible reductions for the C16 strength class		
14.3	7600	370

Total number of specimens in the C16 strength class is 39 (49.75%).

The 5^{th} percentile value for strength in Table 2 (28.01 N/mm^2) exceeds the target value for the C16 strength class of 14.3 N/mm^2 and is also well above the target value for C24 strength class (21.43 N/mm^2) indicating that the machine setting has not correctly selected material appropriate to the C16 strength class. The mean stiffness is inline with expectations for the C16 strength class but the density is well above the target value and exceeds the value for the C24 strength class (shown in Table3).

Table 3. The results for the sample population selected by the C24 settings

Strength (5^{th} percentile) N/mm^2	Mean stiffness N/mm^2 (at 12% moisture content)	Density kg/m^3 (at 12% moisture content)
Data from test sample		
31.03	**10861.6**	**462.6**
Target values with permissible reductions for the C24 strength class		
21.43	10450	420

The total number of specimens in the C24 strength class is 6 (4.8%).

All the values for the C24 strength class in Table 3 have been met but the 5^{th} percentile strength approaches the target value for the C35 strength class and the mean density is inline with the C30 strength class. Only the result for stiffness is of the order of magnitude expected for the C24 strength class.

Table 4. The results for the reject sample population

Strength (5^{th} percentile) N/mm^2	Mean stiffness N/mm^2 (at 12% moisture content)	Density kg/m^3 (at 12% moisture content)
21.03	8785.6	435

The total number that would have been rejected is 35 (43.75%).

The reject material in Table 4 has a 5^{th} percentile value for strength and mean density more inline with the expectation of a C24 strength class, whilst the stiffness exceeds that of the C16 strength class. Therefore, for this material to be graded as reject clearly shows the inappropriate nature of the machine settings for this material.

It is apparent from the results for this sample (Tables 2 to 4) that the machine settings for normal structural timber do not grade appropriately. There is little overall differentiation of the values within each of the possible grades; reject, C16 and C24.There is a slight trend of increasing values for the measured parameters with increasing strength class but this is not inline with correct grading. The values for rejected material is well above the requirements of the C16 strength class and if the timber had been appropriately graded this would not have resulted. Therefore, it can be said that these machine settings do not grade laminated timber correctly.

3.2.2 BS 5268 settings.

Set out in Tables 5 to 6 are the results for the grading using the current BS 5268 machine settings for the strength class combination C16 / C24.

Table 5. The results for the sample population selected by the C16 settings

Strength (5^{th} percentile) N/mm^2	Mean stiffness] N/mm^2 (at 15% moisture content)	Density kg/m^3 (at 12% moisture content)
Data from test sample		
21.18	**8868.45**	**431.65**
Target values with permissible reductions for the C16 strength class		
14.88	8360	370

The total number of specimens in the C16 strength class is 21 (26.2%).

It can be seen in Table 5 that the 5^{th} percentile value for strength approaches the target value for the C24 strength class rather than the target value for the C16 strength class and the density exceeds that of the C24 strength class. Only the stiffness is of an appropriate magnitude for the C16 strength class.

Table 6. The results for the sample population selected by the C24 settings

Strength (5^{th} percentile) N/mm^2	Mean stiffness N/mm^2 (at 15% moisture content)	Density kg/m^3 (at 12% moisture content)
Data from test sample		
27.52	**9544.75**	**449.13**
Target values with permissible reductions for the a C24 strength class		
21.42	10260	420

The total number in the C24 strength class is 45 (56.2%)

In Table 6 the 5^{th} percentile value for strength exceeds the target value for the C30 strength class and the mean density approaches that of the C27 strength class. However, the stiffness is well below the target value for the C24 strength class, there is clearly a misalignment of the strength /stiffness relationship in this sample.

The total number of specimens that would have been rejected is 4 (5%).

The overall grading of this sample (47 mm x 100 mm) and regardless of origin of the machine settings (BS 5268 or EN338) shows that laminated timber can not be correctly graded using settings derived for solid timber.

3.3 Sample 38mm x 150mm – two lamellae lay-up

3.3.1 EN 338 settings

Tables 7 to 9 shows the results for the grading to EN 338 settings for this sample and as with the previous sample the results show that the grading has been inappropriate; once again, there is little discernable difference between strength classes.

Table 7. The results for the sample population selected by the C16 settings

Strength (5^{th} percentile) N/mm^2	Mean stiffness N/mm^2 (at 12% moisture content)	Density kg/m^3 (at 12% moisture content)
Data from test sample		
26.15	**9278.7**	**405**
Target values with permissible reductions for the C16 strength class		
14.3	7600	370

The total number of specimens in the C16 strength class is 20 (28.5%).

The results shown in Table 7 for the C16 strength class clearly demonstrate that the 5^{th} percentile value for strength is well above the target value for the strength class and approaches that for the C30 strength class. Both the mean stiffness and mean density are considerably higher than the target values for those properties.

Table 8. The results for the sample population selected by the C24 settings

Strength (5^{th} percentile) N/mm^2	Mean stiffness N/mm^2 (at 12% moisture content)	Density kg/m^3 (at 12% moisture content)
Data from test sample		
26.99	**10650.5**	**441**
Target values with permissible reductions for the C24 strength class		
21.43	10450	420

The total number of specimens in the C24 strength class is 39 (55.7%).

The 5^{th} percentile value for strength in Table 8 is very close to the 5^{th} percentile value for strength in Table 7 (26.99 N/mm^2 compared to 26.15 N/mm^2) and both approximate to the target value for the C30 strength class, however, one value has been derived by grading to a C24 machine setting and the other derived by

grading to a C16 machine setting. This clearly shows that this sample of laminated timber graded using the new EN338 settings does not give appropriate results.

Table 9. The results for the reject sample population

Strength (5^{th} percentile) N/mm^2	Mean stiffness N/mm^2 (at 12% moisture content)	Density kg/m^3 (at 12% moisture content)
21.82	7585	400

The total number of specimens that would have been rejected is 11 (15.7%).

In Table 9 the 5^{th} percentile value for strength of the reject sample exceeds the target value for the C24 strength class and the mean density exceeds the target value for the C18 strength class. Only the stiffness falls below the target value for the C16 strength class and then it is only marginally below the acceptable value. Once again this reject sample clearly indicates the inappropriateness of the machine settings for strength grading laminated timber.

3.3.2 BS 5268 settings.

Table 10 to 11 show the results for the grading of this sample against the current BS 5268 settings.

Table 10. The results for the sample population selected by the C16 settings

Strength (5^{th} percentile) N/mm^2	Mean stiffness N/mm^2 (at 15% moisture content)	Density kg/m^3 (at 12% moisture content)
Data from test sample		
23.34	9245.5	399
Target values with permissible reductions for the C16 strength class		
14.3	8360	370

The total number of specimens in the C16 strength class is 4 (5.7%).

All the measured values for the properties in this sample (Table 10) exceed the target values for the C16 strength class. The 5^{th} percentile value for strength is above the target value for the C24 strength class, and the mean density is just below the target value for the C18 strength class.

Table 11. The results for the sample population selected by the C24 settings

Strength (5^{th} percentile) N/mm^2	Mean stiffness N/mm^2 (at 15% moisture content)	Density kg/m^3 (at 12% moisture content)
Data from test sample		
26.63	10067.2	425.8
Target values with permissible reductions for the C24 strength class		
21.42	10260	420

The total number of specimens in the C24 strength class is 65 (92.8%).

The results shown in Table 11 show that the 5^{th} percentile value for strength approaches the target value for the C30 strength class rather than the C24 strength class, whilst density is inline with expectations. The result for mean stiffness is blow the target value for the C24 strength class.

The number of rejects was 1 (1.4%).

The overall grading of this sample (38 mm x 150 mm) and regardless of origin of the machine settings (BS 5268 or EN338) shows that laminated timber can not be correctly graded using settings derived for solid timber.

3.4 Sample 38mmx 97mm – two lamellae lay-up

3.4.1 EN 338 settings

The EN 338 grading of this sample, shown in Tables 12 to 14, has the similar kind of results to the previous two samples with no true differentiation between the three graded conditions. The mean stiffness for the C24 strength class is again an issue, being below the target criteria for the strength class.

Table 12. The results for the sample population selected by the C16 settings

Strength (5^{th} percentile) N/mm^2	Mean stiffness N/mm^2 (at 12% moisture content)	Density kg/m^3 (at 12% moisture content)
Data from test sample		
24.69	**9780**	**435.3**
Target values with permissible reductions for the C16 strength class		
14.3	7600	370

The total number of specimens in the C16 strength class is 29 (29%).

In Table 12 (C16 sample) both the 5^{th} percentile value for strength and the mean density exceed the target values for the C24 strength class. The result for mean stiffness is just below the target value for the C22 strength class.

Table 13. The results for the sample population selected by the C24 settings

Strength (5^{th} percentile) N/mm^2	Mean stiffness N/mm^2 (at 12% moisture content)	Density kg/m^3 (at 12% moisture content)
Data from test sample		
26.43	**9791**	**451**
Target values with permissible reductions for the C24 strength class		
21.43	10450	420

The total number of specimens in the C24 strength class is 59 (59%).

The 5^{th} percentile value for strength in Table 13 approaches the target value for the C30 strength class and the mean density exceeds the target value for the C27 strength class, both well above the expectations of the C24 strength class. However, the result for mean stiffness is well below the target value for the C24 strength class and very close to the value for the C16 sample in Table 12, therefore regardless of the results for strength or density this sample does not comply with the requirements of the C24 strength class.

Table 14. The results for the reject sample population

Strength (5^{th} percentile) N/mm^2	Mean stiffness N/mm^2 (at 12% moisture content)	Density kg/m^3 (at 12% moisture content)
18.75	9270	416

The total number that would have been rejected is 20 (20%).

Once again the results for the reject sample (shown in Table 14) all exceed the target values for the C16 strength class and, therefore the material having been graded to the strength class combination Reject / C16 / C24 this is a clear indication of the inappropriate nature of the machine settings for laminated timber.

3.4.2 BS 5268 settings.

This sample, shown in Tables 15 to16, has graded marginally better than the previous samples, but it is still unacceptable. The C16 strength class is inline with what might have been expected.

Table 15. The results for the sample population selected by the C16 settings

Strength (5^{th} percentile) N/mm^2	Mean stiffness N/mm^2 (at 15% moisture content)	Density kg/m^3 (at 12% moisture content)
Data from test sample		
18.75	**9131.16**	**426.57**
Target values with permissible reductions for the C16 strength class		
14.2	8360	370

The total number of specimens in the C16 strength class was 12. (12%).

All the results exceed the target values for the C16 strength class and the mean density exceeds the target value for the C24 strength class. The 5^{th} percentile value for strength is more inline with the expectations of the C16 strength class but still exceeds the target value for the C18 strength class.

Figure 16. The results for the sample population selected by the C24 settings

Strength (5^{th} percentile) N/mm^2	Mean stiffness N/mm^2 (at 15% moisture content)	Density kg/m^3 (at 12% moisture content)
Data from test sample		
26	**9780**	**442.44**
Target values with permissible reductions for the C24 strength class		
21.42	10260	420

The total number of specimens in the C24 strength class was 87 (87%).

In Table 16 the 5th percentile value for strength and the mean density both exceed the target values for the C24 strength class the mean stiffness is considerably lower than the target value of 10260 N/mm^2, therefore this sample regardless of strength and density can not be attributed to the C24 strength class.

The total number of specimens that would have been rejected is 2 (2%).

The overall grading of this sample (38 mm x 97 mm) and regardless of origin of the machine settings (BS 5268 or EN338) shows that laminated timber can not be correctly graded using settings derived for solid timber.

Conclusion and recommendations

1. Laminated Sitka spruce reengineered from falling boards can not be effectively graded using either the current (BS 5268) or the EN 338 settings for solid timber.
2. The relationship between strength and stiffness of the sample timber (falling boards) has been changed by the laminating process such that the strength of the timber has been enhanced but the stiffness has not been increased to the same degree, if at all. As the grading machine uses stiffness to determine the grade the resultant mis-match between strength and stiffness has led to the inappropriate grading.
3. The falling boards appear to have better stiffness characteristics than timber sawn from the bulk of the tress and usually used for structural purposes; this is inline with previous experience and expectations.
4. The density for the three samples was higher than would have been expected from timber usually graded from the main body of the tree. As a result density has not been an issue in this study.
5. The number of laminates did not appear to make a marked difference to the nature of the grading. However, if improved settings are eventually derived differences may become apparent.
6. To effectively grade laminated material a new data base specifically for laminated material will need to be produced and settings derived from it.
7. Before embarking on producing such a data base to derive settings it is essential to ensure effective use of resources and to clearly define the nature of the laminated products to be produced. The industry will need to take ownership of reengineered timber and decided on the nature of the products. Only then will it be worth carrying out any further work with regard to producing effective grade settings.
8. Without full cooperation of the industry in defining the nature of the reengineered timber products they wish to manufacture effective settings can not be derived.
9. At this stage no further work is currently planned on the grading of reengineered timber products without the full and active support of the timber industry. However, there is keen interest within Europe to pursue this area of work as reengineered and value added timber products are seen to the future for the timber industry, as in America.
10. Strength grading machines that do not have stiffness or density as major components of the machine indicating parameter may produce better results to current setting than have been reported in this study.

4 References

1. British Standards Institution 2002, Structural use of timber: Part 2, Code of practice for permissible stress design, materials and workmanship, BS 5268- Part 2: 2002. London
2. British Standards Institution 2003, Structural timber – Strength classes, BS EN 338: 2003. London
3. British Standards Institution 1995, Structural timber - Grading – Requirements for machine strength graded timber and grading machines, BS EN 519: 1995. London
4. British Standards Institution 2004, Timber structures – Strength graded structural timber with rectangular cross section – Part 4: Machine Grading – Grading machine settings for machine controlled system, prEN 14081 – Part 4: 2004: London

Appendix A – Figures for the relationship of machine indicating parameter to measure strength for the three samples

Figure 1. The relationship of machine indicating parameter to measured strength for 47mm x 100mm sample.

Figure 2. The relationship of machine indicating parameter to measured strength for the 38mm x 150mm sample.

Figure 3. The relationship of machine indicating parameter to measured strength for the 38mm x 97mm sample.

Figure 1. Relationship between the machine indicating parameter and measured strength for the 47mm x 100mm sample

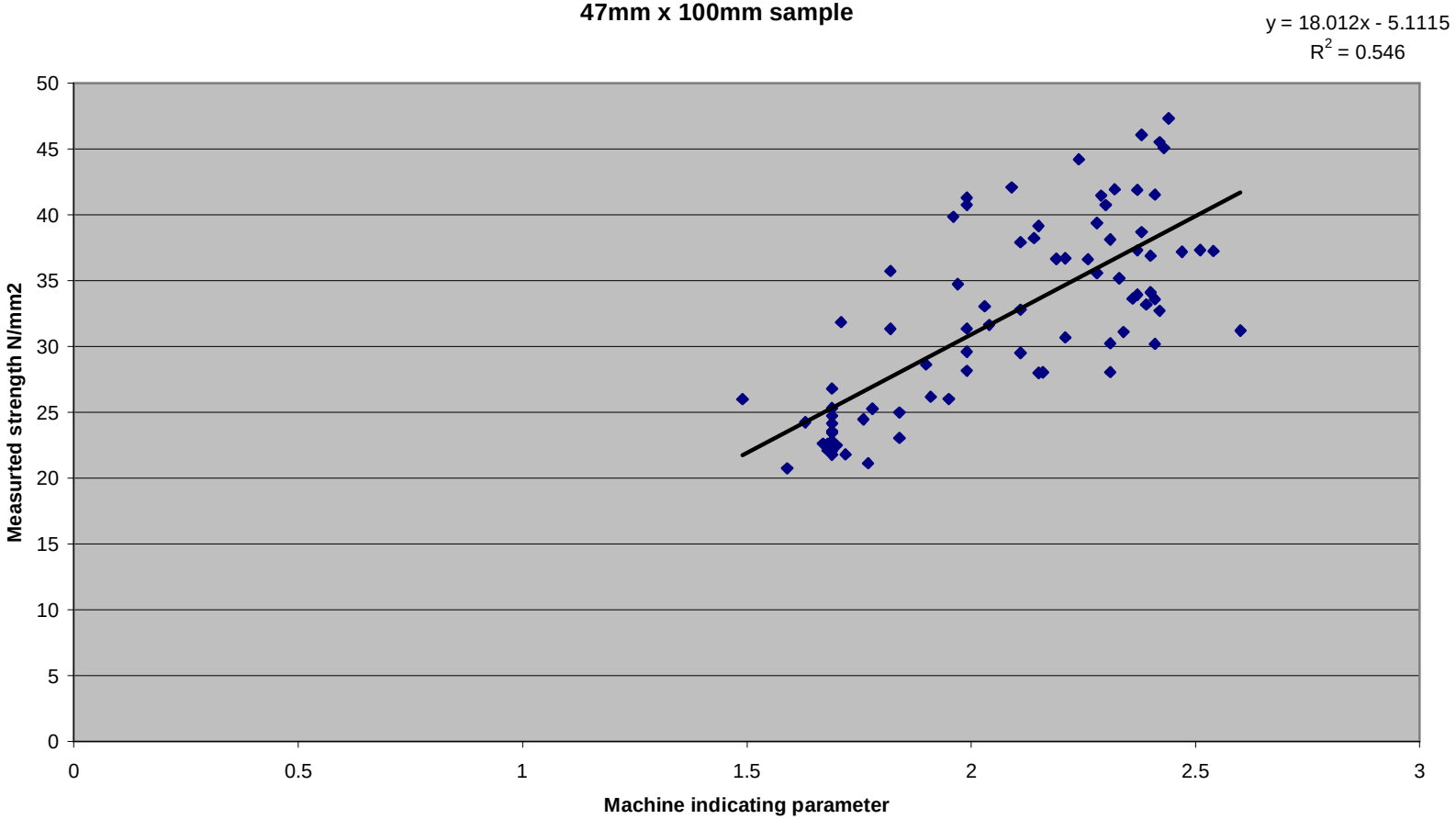

Figure 2. Relationship between the machine indicating parameter and measured strength for the 38mm x 150mm sample

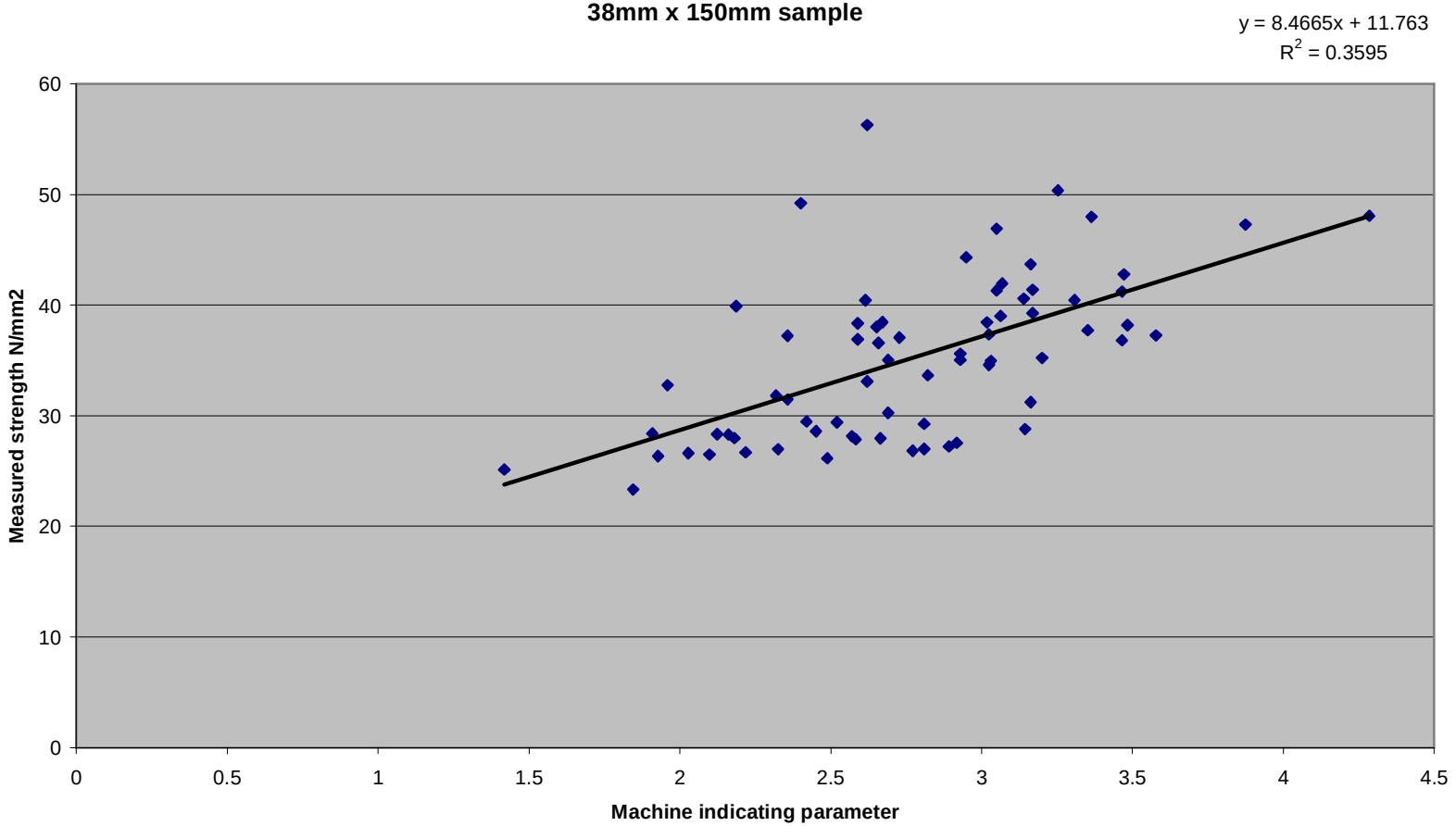

Figure 3. Relationship between the machine indicating parameter and measured strength for the 38mm x 97mm sample