Polish Society of
Composite Materials

Polskie Towarzystwo
Materiałów Kompozytowych

24: 2 (2024) 104-107

**COMPOSITES
THEORY AND
PRACTICE**

ISSN (online): 2299-128X

Łukasz Gorycki*, Piotr Zagulski

Kielce University of Technology, al. 1000-lecia Państwa Polskiego 7, 25-314 Kielce, Poland
**Corresponding author: E-mail: lgorycki@tu.kielce.pl*

Received (Otrzymano) 11.05.2023

ANALYSIS OF INFLUENCE OF SPECIMEN DIMENSIONS ON RELIABILITY OF TENSILE STRENGTH RESULTS

https://doi.org/10.62753/ctp.2024.04.2.2

This paper investigates the influence of the geometric parameters of specimens on the reliability of the obtained tensile strength test results. Based on ISO 527, the shape of the specimens (type 2) and their dimensions were chosen, as well as the test method. The extreme dimensions of the specimens are juxtaposed to illustrate the differences in the tensile strength results.

Keywords: composite, strength, dimension, statistics, accuracy

INTRODUCTION

The dependability of experimental data is crucial in materials science and mechanical testing because it immediately effects our understanding of material behaviour and influences critical engineering decisions. This work is devoted to a thorough study of the significant impact that the geometric factors of a specimen can have on the reliability of tensile strength test results. The study is intended to highlight the often overlooked complexities of materials testing. This will give vital information to researchers, engineers and sectors that rely on accurate data on material properties. It could be an important step in improving the accuracy and credibility of materials testing, which will ultimately advance our collective knowledge in the field of materials science and engineering. Similar studies are shown in [1-5], where the results of the analysis of various types of materials, with different arrangements and different geometries are presented. Although the tests in these articles were carried out on various specimen sizes, there is no reference is made to the ISO 527 standard. In addition, the dimensions of the specimens given in these articles vary considerably, making it difficult to compare the results. It is very important to know the influence of the specimen geometry and quality [6] on its strength parameters. At the same time, there is no information on this subject in the ISO standard. What is important for entrepreneurs and customers is that tests are performed reliably within the existing standards.

MATERIALS AND METHODS

The composite used in this research was made from four layers of 160 g/m^2 glass fabric and Havel L160 resin with LH 147 hardener, $(0°/90°)_4$. Infusion technology was used to manufacture a 500 mm x 500 mm laminate sample. After the stipulated gel time (90 minutes, as specified in the data sheet), the set was placed in the oven with the mould. According to the manufacturer, this resin system should be cured at 50 °C per 1 mm thickness of the finished part and mould. After 3 hours of curing, the sample was left in the oven to cool gradually. After removal from the oven, the sample was de-moulded and prepared to cut out specimens complying to EN ISO 527 [7, 8], specifically type 2 specimens (Fig. 1).

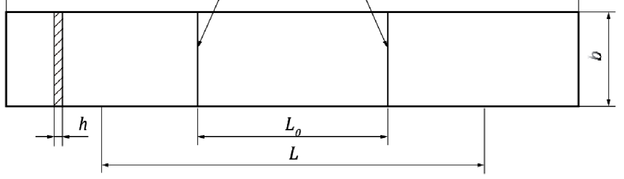

Fig. 1. Shape and dimensions of type 2 specimen according to ISO 527-3, here: distance between jaws L: 100 mm ± 5 mm; width b: from 10 mm to 25 mm; thickness h: ≤ 1 mm; total length l_3: ≥ 150 mm

The samples were cut using a numerically controlled milling machine. Due to the size of the composite plates, four sets of ten specimens each were cut, providing information on the baseline of the tests. The study looked at two variables: width *b* and total length l_3. The width of the specimen was either 10 mm or 25 mm. These dimensions were chosen to assess whether the extreme width dimensions have statistically different effects on the values of the strength parameters. The total length of the specimen was either 150 mm or 250 mm. The first dimension is the lower limit defined by the current standards, while the second dimension is based on older editions of the standard and the most common total length used by manufacturers. The dimensions of the specimens were:

- 10 mm x 150 mm x 1 mm (specimen designation 1015)
- 10 mm x 250 mm x 1 mm (specimen designation 1025)
- 25 mm x 150 mm x 1 mm (specimen designation 2515)
- 25 mm x 250 mm x 1 mm (specimen designation 2525) – example Figure 2.

The number of specimens for each group was 10. A Shimadzu AGX-V 20 kN was utilised to perform static tensile tests.

Fig. 2. Example specimen from 2525 group

RESEARCH RESULTS

Table 1 shows the test results in the form of average values for each group of specimens. Significant differences between the static tensile test results of each group can be observed.

TABLE 1. **Measurement results of static tensile test for tested groups of type 2 plates**

Group	Max force F_{max} [N]	Max stress σ_m [N/mm^2]	Max displacement ΔL_{max} [mm]	Max displacement force [N]	Modulus of compression E_t [GPa]
1015	2100.02	154.93	5.04	1692.64	5.06000
1025	1840.92	138.90	6.27	1560.37	5.67180
2515	5269.05	160.66	5.21	5249.47	5.02000
2525	4860.43	166.08	6.91	4766.34	10.5900

The results for the maximum force and the maximum displacement force are presented in Figures 3 and 4, respectively, where box plots of the results with inclusion of the least squares estimation line are shown. It can be seen that the results for both parameters grow as the width increases. 2.5 times wider specimens resulted in approximately a 2.5-time increase in each parameter. In addition, for these two parameters, the 150 mm long specimens have on average results 10 % higher than the 250 mm long specimens of the same width. The coefficients of variation for the maximum force are as follows: 7.51 %, 4.80 %, 10.30 %, 5.49 % and for the maximum displacement force: 21.31 %, 20.96 %, 10.59 %, 5.68 %. Assuming that if the value of the coefficient of variation is in the range <0 %; 10 %>, we are dealing with a small amount of variability (we can consider such a group as homogeneous); if it is in the range (10 %; 25 %> we are dealing with a small amount of variability, and hence we can assume that the variability for all 4 groups is satisfactory.

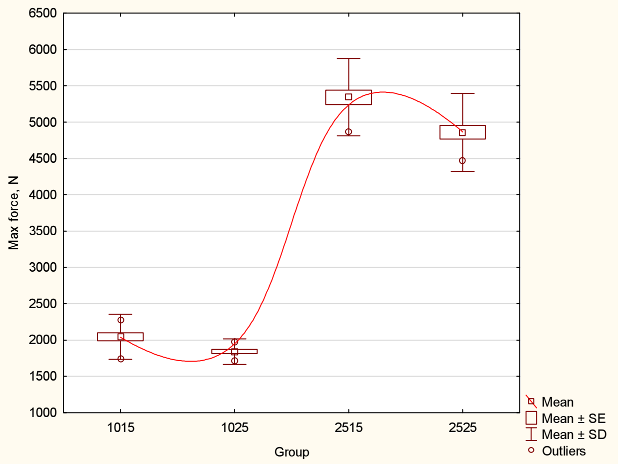

Fig. 3. Measurement results of max force for 4 specimen groups

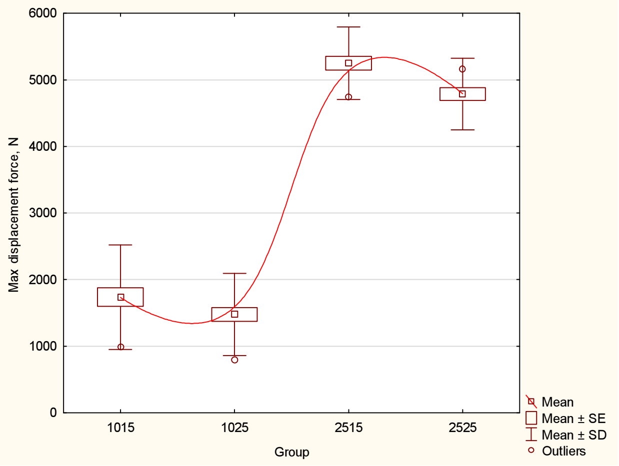

Fig. 4. Measurement results of max displacement force for 4 specimen groups

From the results of the maximum displacement (Fig. 5), the effect of the length of the specimen on the results of both parameters can be observed. In the case of displacement, the change is greater for the longer specimens (250 mm), where the deformation relative to the initial change in length is approximately 1 %. The coefficients of variation for the maximum displacement are, respectively, 12.08 %, 9.12 %, 14.05 %, 9.50 %.

The results for the maximum stress (Fig. 6) cannot be described in the same way as the previous graphs. By comparing specimens 1015 and 2515, it can be concluded that changing the width of the specimen has a slight effect on these parameters. However, in the case of specimens 2515 and 2525, the results indicate a significant effect of the width of the specimens on both parameters. It is worth considering whether the measurement results have been influenced by factors not taken into account, such as possible minor defects in specimens 1025 and 2525, which may have affected the measurement results but not the other parameters. The coefficient of variation for the maximum stress are: 7.51 %, 4.80 %, 10.30 %, 5.49 %.

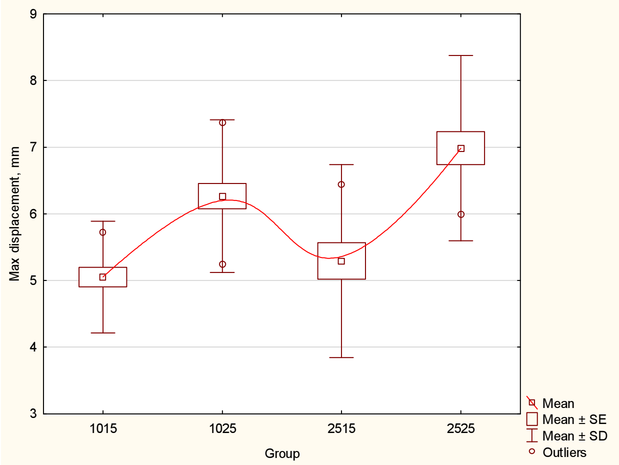

Fig. 5. Measurement results of max displacement for 4 specimen groups

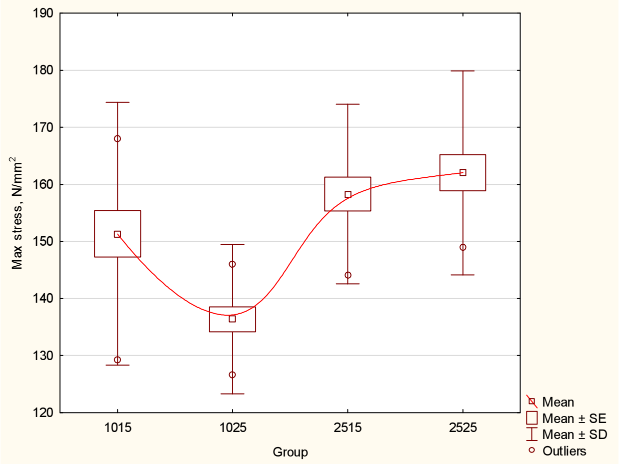

Fig. 6. Measurement results of max stress for 4 specimen groups

The differences in the results for the modulus of compression (Fig. 7) may correlate to some extent with the results of the maximum stress. In this context, it is important to consider the possibility that the 2525 specimens are defective due to errors in the cutting of them or in the measurements. Further comparative analysis of these specimens with ones made in the same way should help to finding the answer to the question of what the source of such results is. If the values of these two parameters are the result of sample preparation, the next steps should be to determine the causes of these results and to develop a method of controlled sample preparation that does not affect these parameters or affects them in a controlled manner. If there are other causes of such values, the next steps should be to determine what caused them and to develop ways to avoid them in the future.

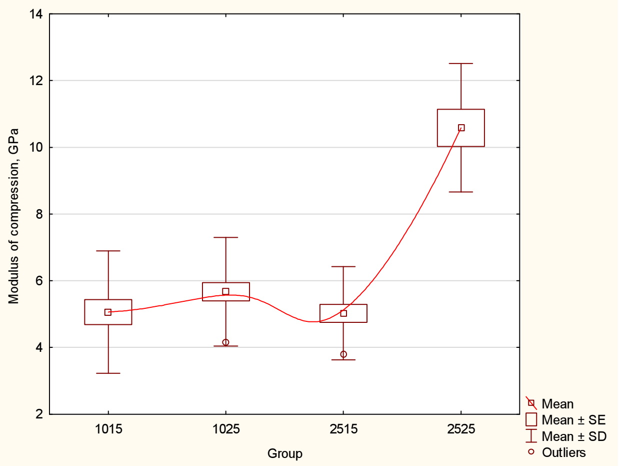

Fig. 7. Measurement results of modulus of compression for 4 specimen groups

STATISTICAL ANALYSIS

A general linear analysis method based on regression modelling was employed to analyse the quantitative effect of specimen width and total length (independent variables) on the static tensile test parameters (dependent variables) [9, 10].

This approach allows us to describe the relationship between the dependent and independent variables using the general formula (1):

$$y = b_0 + b_1x_1 + b_2x_2 + \cdots + b_nx_{n,} \tag{1}$$

where: y – dependent (explanatory) variable; b_0 – free expression; b_1, b_2, b_n – regression coefficients; x_1, x_2, x_n – independent (explanatory) variables; n – number of predictors.

Regression analysis can be used to determine how independent variables influence dependent variables and the strength of these influences. This analysis can help to identify the factors that most influence the values of the dependent variables and which should be controlled or changed to achieve the desired results. A significance p-value = 0.05 was applied for the significance tests.

Using Statistica software and based on experimental studies, Formula (1) was transformed to obtain general linear models to evaluate the effect of the width b value and the total length l_3 of the specimen on the analysed parameters:

$$\text{Max force} = 854.03 + 191.60 \cdot b - 4.10 \cdot l_3 \tag{2}$$

$$\begin{aligned}\text{Max displacement force} = &- 92.84 + \\ &+ 220.52 \cdot b - 2.47 \cdot l_3\end{aligned} \tag{3}$$

$$\text{Max displacement} = 2.78 + 0.02 \cdot b + 0.01 \cdot l_3 \tag{4}$$

$$\text{Max stress} = 146.10 + 0.73 \cdot b - 0.04 \cdot l_3 \tag{5}$$

$$\text{Modulus of compression} = -0.51 + 0.15 \cdot b - 0.02 \cdot l_3 \tag{6}$$

TABLE 2. **Results of coefficient of determination R^2 and p-value for equation and p-value independent variables**

	equation	R^2	p	p_b	p_{l3}
Max force	(2)	0.87	$2.6 \cdot 10^{-15}$	0	0.044
Max displacement force	(3)	0.95	0	0	0.059
Max displacement	(4)	0.55	0	0	0.17
Max stress	(5)	0.18	0.03	0.02	0.31
Modulus of compression	(6)	0.24	0.01	0.03	0.03

On the basis of Tables 1 and 2, the graphs (Figs. 3-7) and the mathematical models (2)-(6), it can be seen that the parameters fall into three groups.

The first group is the maximum force and the maximum displacement force. Both of these parameters are highly dependent on the geometry of the specimens (particularly the width). The source of inaccuracies in the models may be due to inaccuracies in the measurements themselves, the specimens or other factors that significantly affect these parameters.

Group two is the maximum displacement. In this case, the geometry of the specimen has a significant effect on the results, but there may be other factors that have a similar effect. Further research should include an analysis of what these factors are and how they affect the values of this parameter.

Group three is comprised of the maximum stress and the modulus of compression. For this group, it can be assumed that the geometry has a small but statistically significant effect on the final result. Further research should investigate the factors that influence these two parameters.

CONCLUSIONS

The influence of numerous elements on the static tensile test parameters of composites is complex and requires considering several variables, including specimen geometry. The specimen thickness is closely related to the type of material used and the number of layers, making precise control of this parameter a challenge. In contrast, ISO 527-3 limits the width and total length of the specimens, but both dimensions can be chosen within defined ranges. Nonetheless, this standard does not specify how these dimensions affect the test results or how they should be used for specific testing purposes.

The results show that the specimen width and total length have a significant effect on parameters such as the maximum force and the maximum displacement force. The influence on characteristics such as the maximum displacement is small, mainly by the total length. The specimen width and total length have little effect on the parameters such as the maximum stress and modulus of compression. Nevertheless, the potential influence of other factors on the test results should be considered.

In conclusion, the total length and width have an influence on the static tensile test parameters. Measurements on specimens with different geometries should be included in future studies. At the same time, measurements should be made on identically constructed specimens to ensure that the results reported in the article are free from significant errors.

REFERENCES

[1] Wisnom M.R., Khan B., Hallett S.R., Size effects in unnotched tensile strength of unidirectional and quasi-isotropic carbon/epoxy composites, Composite Structures 2008, June, 84, 1, 21-28, DOI: 10.1016/j.compstruct.2007.06.002.

[2] Sutherland L.S., Shenoi R.A., Lewis S.M., Size and scale effects in composites: I. Literature review, Composite Structures 1999, February, 59, 2, 209-220, DOI: 10.1016/S0266-3538(98)00065-7.

[3] Sutherland L.S., Shenoi R.A., Lewis S.M., Size and scale effects in composites: II. Woven-roving laminates, Composite Structures 1999, February, 59, 2, 235-251, DOI: 10.1016/S0266-3538(98)00106-7.

[4] Wisnom M.R., Size effects in the testing of fibre-composite materials, Composites Science and Technology 1999, October, 59, 13, 1937-1957, DOI: 10.1016/S0266-3538(99)00053-6.

[5] Lamon J., R'Mili M., Investigation of specimen size effects on p-quantile diagrams and normal distributions of critical flaw strengths in fiber tows, Journal of Composites Science 2022, 6, 6, DOI: 10.3390/jcs6060171.

[6] Chatys R., Piernik K., Modelowanie właściwości mechanicznych wyrobów lotniczych wytworzonych z kompozytów wzmocnionych włóknami, Przetwórstwo Tworzyw 2015, 168, 6, 440-446.

[7] PN-EN ISO 527-1:2012 Tworzywa sztuczne -- Oznaczanie właściwości mechanicznych przy statycznym rozciąganiu – Część 1: Zasady ogólne.

[8] ISO 527-3:2018 Plastics – Determination of tensile properties – Part 3: Test conditions for films and sheets.

[9] Muciek A., Wyznaczanie modeli matematycznych z danych eksperymentalnych, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2012.

[10] Stanisz A., Przystępny kurs statystyki z zastosowaniem STATISTICA PL na przykładach z medycyny. Tom 2. Modele liniowe i nieliniowe. StatSoft Polska, Kraków 2007.