Proceedings of the IASS 2024 Symposium
Redefining the Art of Structural Design
August 26-30, 2024, Zurich Switzerland
Philippe Block, Giulia Boller, Catherine DeWolf,
Jacqueline Pauli, Walter Kaufmann (eds.)

Inaccuracy of Testing Speed in Determination of Tensile Properties of ETFE Membranes according to ISO 527

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Abstract

The International Standard ISO 527 Plastics – Determination of tensile properties – [1] is designed to investigate the tensile behaviour of the test specimens and for determining the tensile strength, Young's modulus and other aspects of the stress/strain relationship under the conditions defined in the standard. Results are used for the purpose of material analysis, research and development, quality assurance, and structural analysis and design. The test method is adopted by material suppliers to provide the mechanical material parameter for the Certificate of Analysis according to EN 10204-3.1 [2]. Inter alia, different test speeds are recommended ranging between 0,125 and 500 mm/min. Since the stress/strain relation of ETFE foils is sensitive regarding the strain rate, prCEN TS 19102 [3] defines a constant strain rate of 200%/min referring to the clamping length of the sample of 50 mm. Thus, special attention should be paid to the control of a constant strain rate.

The strain rate performance of three different calibrated tensile test machines comprising different software packages and electronics was analysed. For all machines, the pre-set test speed could be achieved only after a few seconds. Accordingly, the defined strain rate for the determination of the Young's modulus ($0.1\% \leq \varepsilon \leq 1\%$) as well as the yield point were passed before a constant strain rate was achieved.

The applicability of ISO 527 [1] for the specification of the mechanical performance of ETFE foils for architectural applications will be discussed.

Keywords: membranes, tensile test, testing speed, strain rate, testing inaccuracy, material specifications.

1. Introduction

ISO 527 [1] serves as a foundational standard within the field of materials testing. It provides a structured methodology for evaluating the mechanical behavior of materials under tension. This internationally recognized standard delineates the procedure for determining key parameters, such as tensile strength, Young's modulus, and elongation at break, offering valuable insights into the material's response to applied forces.

The importance of ISO 527 [1] spans across various industries, and it serves as an indispensable tool for material characterization, research and development, quality assurance, and structural design. Manufacturers, researchers, and engineers rely on its guidelines to accurately assess and compare the mechanical properties of materials, enabling informed decision-making throughout the product development lifecycle.

One of the notable features of ISO 527 [1] is its adaptability to different types of materials and testing conditions. The standard provides comprehensive guidance on specimen preparation, testing apparatus, and testing parameters. It ensures consistency and reproducibility of results across various laboratories and testing environments.

However, despite its robust framework, ISO 527 [1] is not without limitations. Variations in testing conditions, such as temperature, humidity, and strain rate, can significantly influence the material's behavior during testing. Therefore, strict adherence to relevant standards and careful consideration of these factors are essential in ensuring accurate and meaningful test results.

This paper aims to delve into the application and effectiveness, or lack thereof, of ISO 527 [1] in characterizing the mechanical performance of plastic materials, with a specific focus on its relevance in architectural applications. By examining the standard's practical considerations, we seek to evaluate its suitability for assessing the tensile properties of ETFE used in architectural design and construction. Through this analysis, we aim to contribute to a deeper understanding of material selection and performance optimization in the field of architecture. Widely adopted across industries, ISO 527 [1] provides crucial parameters for material analysis, research, and quality assurance. However, its application on specific materials, such as ETFE foils used in architecture, requires further deliberation and improvement due to factors like material strain rate sensitivity.

2. Experimental procedure

The strain rate performance of three calibrated tensile test machines has been studied, each machine featuring distinct software and electronics. One of these machines was produced by a German manufacturer (machine 1). The other two machines are produced by Italian brand (machines 2 and 3). All machines were subjected to various testing speeds to comprehensively evaluate their performance. ETFE foils with a thickness of 250 micrometers was used for the tests. All tensile tests were carried out at room temperature 23±2°C.

Figure 1: Tensile test set-up with clamping distance of 100 mm.

Significant delays in attaining the pre-set test speeds were identified for all three machines. These delays had a considerable impact on the consistency of strain rates, thereby affecting the accuracy of material characterization. It is worth noting that there was a discernible lag of several seconds before reaching the desired test speed, resulting in critical test inaccuracy. This delay poses a substantial risk in obtaining precise and reliable results, potentially introducing inconsistencies in the assessment of material properties.

Furthermore, these findings have implications beyond mere operational efficiency. They address concerns regarding the applicability and trustworthiness of the data generated by these testing machines using ISO 527 [1] standard, particularly in industries where precise material properties hold paramount importance, including sectors, such as aerospace, automotive, construction, and manufacturing.

Addressing these disparities in strain rate performance is crucial in upholding the integrity of material testing practices and providing concrete evidence for subsequent engineering decisions [9].

The pre-set test speeds determine how quickly the tensile force is applied to the specimen, allowing uniformed and reliable comparison of test outcomes across various laboratories and testing environments. Throughout the test, the specimen is firmly secured with the clamping devices and is being pulled until it fractures. Simultaneously, the testing apparatus continually monitors both the force applied during the pulling and the elongation of the specimen, providing comprehensive data throughout the testing process [10].

The spacing between clamping devices according to ISO 527 [1] may vary based on the version of the standard and the specimen type. Nevertheless, for the majority of standard tensile tests adhering to ISO 527 [1], the common clamping distance is approximately 100 mm. This distance allows the specimen to be securely held in place and properly aligned within the testing machine during the tensile tests. It is important to note that all samples in this study were tested using this standardized clamping distance of 100 mm.

2.1. Tensile test according to ISO 527 [1] for ETFE material with pre-set test speed of 50 [mm/min]

Figure 2 depicts the stress and strain values of the specimens on each machine tested with the pre-set speed over time. Among three machines used during the tests, machine 3 reached the desired speed within the shortest amount of time – reaching 50 mm/min in just 1.56 seconds, accompanied by an elongation of 1.21 %. The tensile test machine 1 followed closely behind, achieving the same speed in 1.90 seconds. Machine 2, on the other hand, took 3.30 seconds to reach the designated speed, with an elongation of 1.97 %.

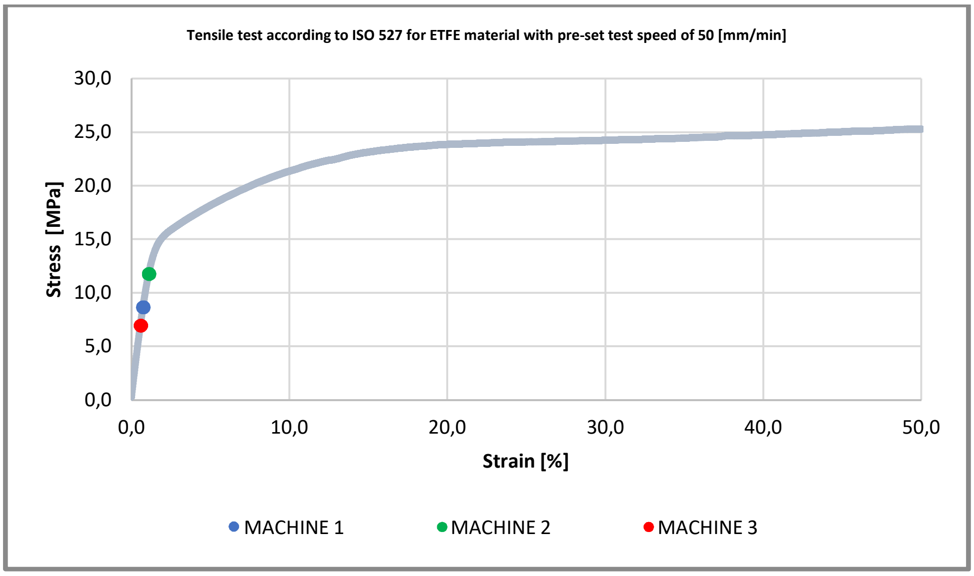

Figure 2: Stress and strain values at which each machine achieved the pre-set speed of 50 [mm/min] at 100 mm clamping length.

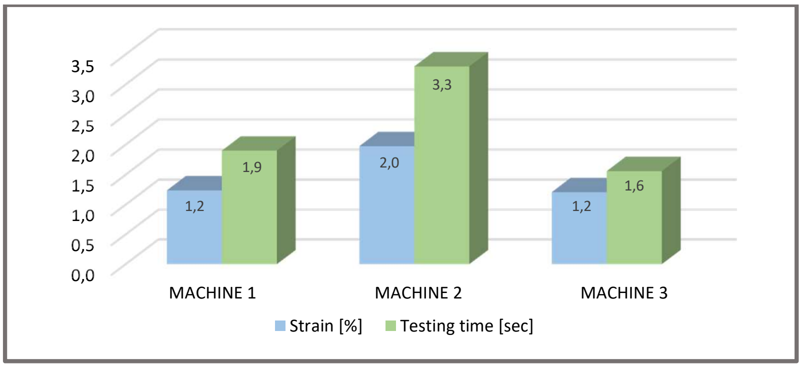

Figure 3: Relation between strain and testing time with the pre-set speed of 50 [mm/min] at 100mm clamping length.

2.2. Tensile test according to ISO 527 for ETFE material with pre-set test speed of 100 [mm/min]

Figure 4 illustrates the tensile tests conducted on both the machine 2 and 3, demonstrating that both machines required a similar amount of time to reach the pre-set test speed. The elongation for both machines is 1.67 %. In contrast, the machine 1 exhibits a notably slower performance, requiring 3.55 seconds to reach its peak speed. The elongation for this machine is recorded at 5.29 %.

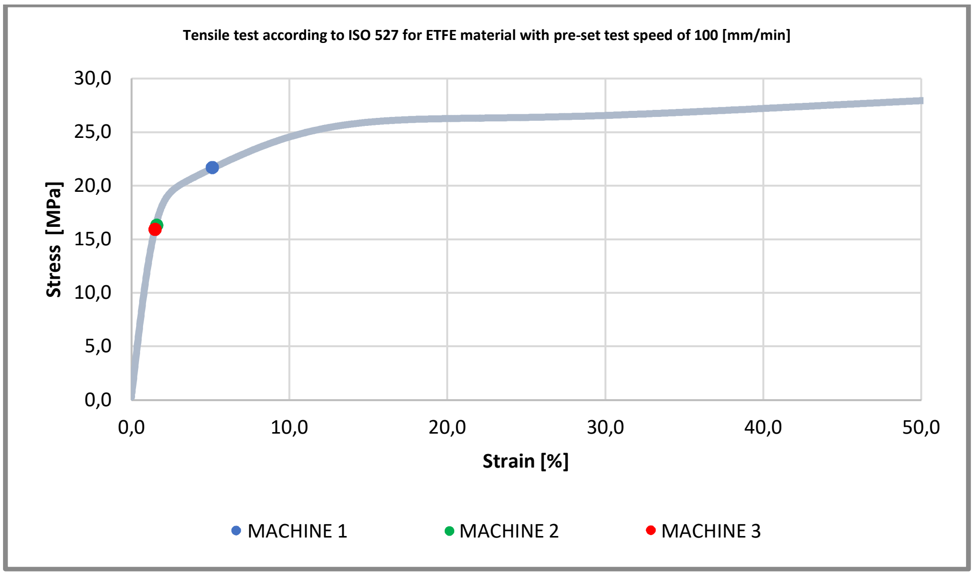

Figure 4: Stress and strain values at which each machine achieved the pre-set speed of 100 [mm/min] at 100mm clamping length.

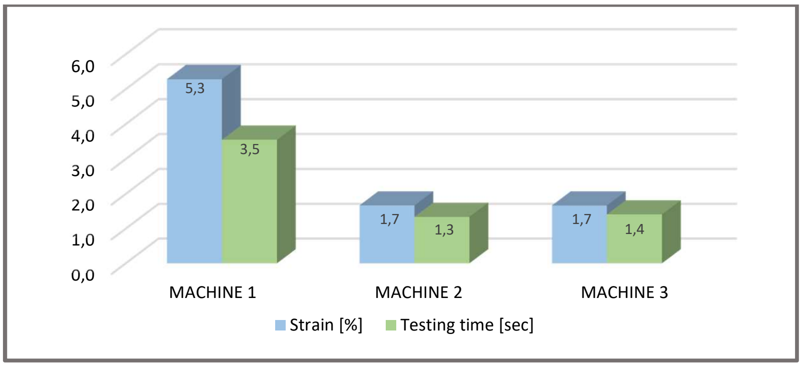

Figure 5: Relation between strain and testing time with the pre-set speed of 100 [mm/min].

2.3. Tensile test according to ISO 527 for ETFE material with pre-set test speed of 500 [mm/min]

Figure 6 provides insight into the time required for each machine to attain a speed of 500 mm/min. The machine 1 took over 5 seconds to reach the desired speed, while the other two machines only required around 2 seconds. The difference between the machine 1 and the other two machines is rather significant.

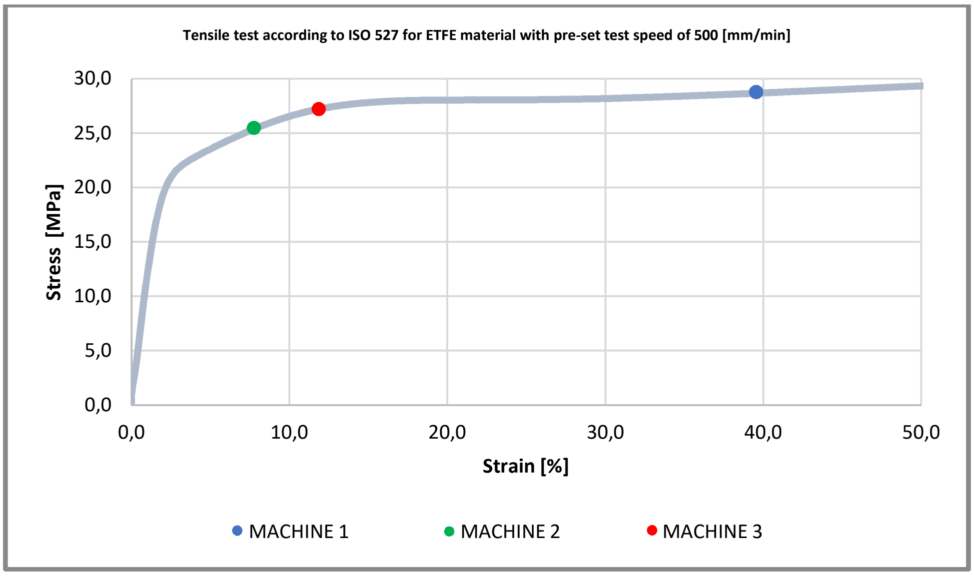

Figure 6: Stress and strain values at which each machine achieved the pre-set speed of 500 [mm/min] at 100mm clamping length.

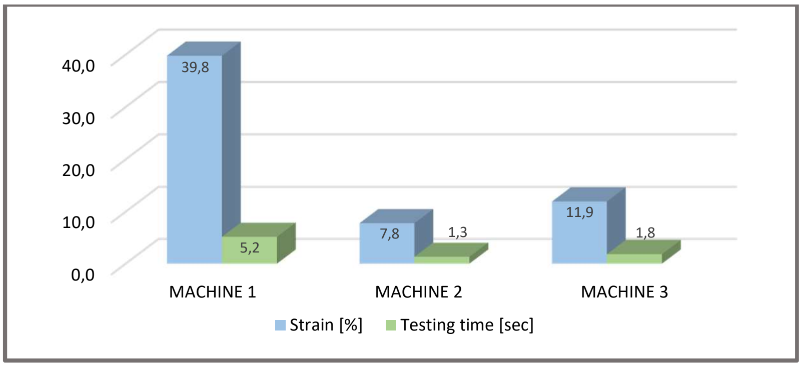

Figure 7: Relation between strain and testing time with the pre-set speed of 500 [mm/min].

3. Conclusion

The first edition of ISO 527 has been published in 1993 under the title Plastics – Determination of tensile properties and consists of five parts:

Part 1: General principles

Part 2: Test conditions for molding and extrusion plastics

Part 3: Test conditions for films and sheets

Part 4: Test conditions for isotropic and orthotropic fiber-reinforced plastic composites

Part 5: Test conditions for unidirectional fiber-reinforced plastic composites

This paper highlights the importance of ISO 527 [1] in materials testing in general while acknowledging its limitations, concerning the strain rate sensitivity. By addressing challenges and proposing solutions, it seeks to enhance the reliability and accuracy of material testing practices and to facilitate informed decision-making in engineering and design, especially for architectural applications.

Due to its significant impact on a broad spectrum of industries, the ISO 527 guidelines [1] are relied upon by manufacturers, researchers, and engineers to accurately assess and compare the mechanical properties of materials.

In this study, focus was set on evaluating the strain rate performance of three calibrated tensile test machines when testing ETFE foils. The detailed analysis revealed significant delays in attaining pre-set test speeds across all machines, impacting the consistency of strain rates and potentially compromising result accuracy. Addressing these operational inefficiencies is a crucial first step towards protecting the integrity of material testing practices and better understanding not only of the ETFE foils but also of other plastic materials where tensile properties shall be determined.

Furthermore, the examination of the tensile test results at different pre-set test speeds provided indispensable information regarding the performance of the three tensile test machines. Accordingly, the working range of each of the machines is limited and strongly depends on the strain rate chosen for the test. For ETFE foils, specifically the calculation of the Young's modulus as well as the identification of the first and second yield point at a strain rate below 10% are affected. Understanding these variations is essential for decision-making in material selection and design.

In conclusion, while ISO 527 [1] still holds great significance for material testing, addressing disparities in testing conditions and machine performance is crucial to obtain reliable and accurate test results. The test results based on the test procedures at least according to ISO 527-3 Test conditions for films and sheets does not allow for the definition of the material characteristics. Either the test method has to be updated according to the limitations discussed before, or the tensile test machines have to be modified in order to provide a constant strain rated even at the start of elongation of the sample.

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