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TENSILE TESTING OF FLAT THIN SPECIMENS USING THE TWO-DIMENSIONAL DIGITAL IMAGE CORRELATION METHOD

ISPITIVANJE ZATEZANJEM TANKIH RAVNIH UZORAKA KORIŠĆENJEM METODE DVO-DIMENZIONALNE KORELACIJE DIGITALNIH SLIKA

Originalni naučni rad / Original scientific paper
UDK /UDC:

Rad primljen / Paper received: 18.01.2023

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Keywords
- 2D Digital Image Correlation
- tensile testing
- flat thin specimens
- textile

Ključne reči
- 2D Korelacija digitalnih slika
- ispitivanje zatezanjem
- ravni tanki uzorci
- tekstil

Abstract

Conventional tensile testing is most commonly used for determining the basic mechanical properties of the material. However, this approach is challenging for in-depth analysis of material behaviour, especially related to heterogeneous materials. The Digital Image Correlation (DIC) method is a contactless optical method that overcomes the constraints of traditional experimental methods (e.g., strain gauge) and allows for full-field displacement and strain measurement. The paper specifically covers 2D-DIC application on tensile testing thin flat specimens prepared using cotton textile with 130 g/m^2 density. Results show significant differences in von Mises strain values over the surface of the specimen, ranging from 8 to 24 %. The application of 2D-DIC in this case shows the significance of full-field analysis, as conventional usage of the tensile test would have missed the difference in mechanical properties of adjacent areas on the same specimen. 2D-DIC provides high spatial resolution, accuracy, real-time data acquisition, and visualization, making it a valuable tool for characterizing mechanical properties of thin flat specimens and understanding deformation mechanisms.

Izvod

Konvencionalno ispitivanje zatezanjem se najčešće koristi za određivanje osnovnih mehaničkih karakteristika materijala. Međutim, ovaj pristup predstavlja izazov za detaljniju analizu ponašanja materijala, posebno sa heterogenim materijalima. Metoda korelacije digitalnih slika (DIC) je beskontaktna optička metoda koja prevazilazi ograničenja tradicionalnih eksperimentalnih metoda (na pr. mernih traka) i omogućava merenje polja pomeranja i deformacija. Ovaj rad se odnosi na primenu 2D-DIC na ispitivanje zatezanjem tankih ravnih uzoraka pripremljenih od pamučnog tekstila gustine 130 g/m^2. Rezultati pokazuju značajne razlike u vrednostima von Mizesove deformacije po površini uzorka, u rasponu od 8 do 24 %. Primena 2D-DIC, u ovom slučaju, pokazuje značaj analize celog polja, pošto bi konvencionalna upotreba ispitivanja zatezanjem propustila razliku u mehaničkim svojstvima susednih oblasti na istom uzorku. 2D-DIC obezbeđuje visoku rezoluciju, tačnost, prikupljanje podataka u realnom vremenu i vizuelizaciju, što je čini vrednim alatom za karakterizaciju mehaničkih svojstava tankih ravnih uzoraka i za razumevanje mehanizama deformacije.

INTRODUCTION

The conventional tensile measurement system with contact displacement/strain gages is often more appropriate for small and homogeneous strain deformations of the loaded sample. In engineering practice, the majority of loaded samples, however, experience heterogeneous deformation rather than rigid uniform deformation. In this situation, it could be challenging to describe the information about the problematic area from the strain gauge data that is located at discrete places. The requirement for full-field noncontact techniques is particularly critical in order to handle this problem and prevent damage to the sample itself. Many full-field detection techniques based on optical pattern recognition have emerged after decades of advancements in noncontact measurement technology, including Digital Image Correlation (DIC). Among these optical techniques, DIC, created in the early 1980s, has numerous distinct benefits, including very easy measuring system preparations and lower experimental environment requirements and high automation in measurement processing, /1, 2/.

Following its initial proposal in the 1980s and subsequent continuous improvement, DIC has received extensive applications in a variety of domains, including fracture mechanics, elastic mechanics, tensile testing, and three-point bending. Digital Image Correlation Method /1/, a non-contact optical technique, allows for full-field displacement and strain measurement while getting beyond the drawbacks of traditional experimental techniques (such as strain gauges). Large datasets can be acquired by a single experiment, replacing several strain gauges and drastically reducing the time and expense required to set up the experiment. Furthermore, since numerical methods calculate full displacement and strain fields, a model may be quickly confirmed by comparing it with actual data that is also displayed in this form. A more precise theoretical analysis is made possible by accurate experimental determination of critical areas, or areas with the highest strain values, as well as principal stress orientations, /3/.

The DIC can be classified into two main categories: two-dimensional (2D-DIC) and three-dimensional (3D-DIC). 2D-DIC involves analysis of image data in two dimensions, providing information about in-plane displacements and strains of the image. Advantages of 2D-DIC include low computational demands and the ability to process a large number of image frames in real time. 3D-DIC, on the other hand, allows for the analysis of objects with more complex deformations by incorporating depth information /4-6/. The technique involves capturing multiple images of the same object from different angles and using the information to generate a 3D model. The 3D-DIC provides more accurate and detailed information about an object's deformation, but it also has higher computational demands and is more time-consuming to process, /4-12/.

The aim of this paper is to measure flat thin textile specimens in plane strain using the 2D-DIC method. The 2D-DIC method has been fully developed and matured in the past two decades and the paper focuses on the 2D-DIC testing preparation and experimental setup, but also the advantages and disadvantages of the method.

MATERIALS AND METHODS

2D-DIC basic information

The fundamentals of early DIC were in-plane displacement and strain measurement applications for solid mechanics measurements. A nominally flat specimen was tested for tension in each case. It was believed that only the planar specimen surface would deform during testing. So, while measuring object motion using 2D-DIC, three main assumptions are usually used, /13/:

- first, the specimen is considered to be nominally planar;
- second, the object plane is parallel to the sensor plane;
- third, the specimen is loaded and deformed within the original object plane.

For originally flat specimens, this assumption holds true, at least roughly, whether or not there are certain geometric discontinuities (such as fractures, notches, or intricate cut-outs), or gradients in the material properties. In general, it is assumed that an item that is ostensibly planar is subjected to a combination of in-plane tension, shear, or biaxial loading so that the specimen primarily deforms inside the original planar surface. Poisson's effect in the crack tip region (which causes slight out-of-plane motion) is expected to be minimal in comparison to the applied in-plane deformations when cracked or notched specimens are loaded. The presumption holds true when similarly loaded planar specimens with gradients in material properties are used.

Textile material specifics

Strength and durability of a textile material are crucial factors in determining its quality and performance. Industrial standards for fabric and clothing quality assurance focus mainly on these two aspects as they play an essential role in the functioning of the final product made from these materials. The principles behind the standardized tests for strength and durability were initially developed for solid engineering materials due to the potential consequences of their failure. These tests and theories have since been adapted for textile materials and are now widely used in the industry, /13-14/.

One of the most common standardized tests for textile strength and durability is tensile testing on standardized specimens. Simple tensile loading is one of the basic types of loading applied to sheet-like materials like fabrics. In a tensile test, the fabric is stretched until it breaks, and the maximal loading at which this occurs is called the breaking load. The material's ultimate strength and breaking strain are calculated from this value and provide an indicator of the material's strength under tensile load. The nature of fabrics, specifically their fibres, allows for movement under loading, which leads to scientific challenges in understanding their fracture behaviour and failure criteria. Woven fabrics are well-known for their property-direction dependence and susceptibility to external loading, making their prediction of strength both theoretically and practically significant. There are several experimental methods for strength prediction, including the Digital Image Correlation method, one of the most established and widely used optical methods for characterizing fabric properties, /15/.

Testing procedure and experimental setup

Tensile testing of flat specimens requires special care and independent simultaneous measurement of strains or numerical simulation, especially in the case of small thickness, /16-19/. The process for performing uniaxial tensile testing on a planar textile specimen is given in the standard EN ISO 13943-1 /20/. EN ISO 13943-1 specifies a strip method for establishing the maximum force and equivalent elongation of textile textiles. The approach is mostly used on woven textiles, including fabrics with stretch qualities conferred by the presence of an elastomeric fibre, mechanical treatment, or chemical treatment /20/. To ensure that the experimental setup (Fig. 1) is accurately calibrated and ready for use, the following test procedure should be conducted:

1. *Specimen preparation*. Strip specimens with dimensions 50 × 350 mm are constructed according to /20/, as illustrated in Fig. 1. Measurement requires data of the surface structure. To clearly allocate the pixels in the camera photos, the specimen's surface must have a pattern (facets). As a result, a pixel area in the reference image can be assigned to a pixel area in the target image. To create a random high-contrast stochastic pattern, one surface of the specimen is coated with black paint dots.
2. *2D-DIC system calibration*. All photographs are captured with a 50 mm lens and acA-1920 Basler camera (Basler, Germany) at a resolution of 2 MP. A LED lamp offered continuous specimen lighting during the experiment. The camera was positioned 1.42 m from the specimen.
3. *Specimens positioning*. Specimens were secured using pneumatic grips with flat plates. Pneumatic grips were placed at a spacing of 200 mm apart with a preload of 2.0 N.
4. *Tensile testing machine setup*. All experiments were carried out using a Tinius Olsen H10KT tensile testing

machine (Tinius Olsen, UK) with a maximum loading of 10 kN. Tensile loading was performed utilising displacement control, with the upper grasp moving at a constant rate of 100 mm/min.

5. <u>*2D-DIC system measurement*</u>. For the experiment, images are captured automatically at rate of 1/sec. Tensile loading and picture recording began at the same time.
6. <u>*2D-DIC system data processing*</u>. GOM Correlate software (GOM, Germany) was used to calculate strain after the experiment.

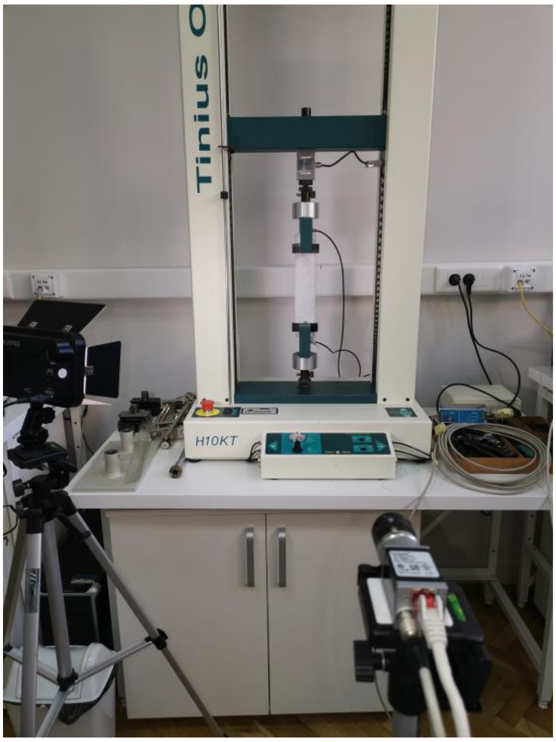

Figure 1. Experimental setup for testing of textile flat specimens.

In this work, three specimens were prepared using cotton textiles with a density of 130 g/m^2.

RESULTS AND DISCUSSION

2D-DIC is a non-contact, full-field measurement technique widely used for tensile testing of thin specimens. The method involves tracking the motion of speckles or markers placed on the specimen surface during deformation. The resulting displacement data can be used to calculate strains and stress in the specimen.

As previously mentioned, the strip tensile specimen experiences complex tensile deformations due to the unique fibre structure under tensile load. Von Mises strain results are presented in this paper, taking into consideration longitudinal and transverse deformations that occur simultaneously during tensile load. The strain field was analysed using two points (Points 1 and 2) and one section (Section 1) parallel to the *x*-axis. Experimental data are also presented graphically as a function of time and section length.

A representative image of von Mises strain field results for maximum axial force before fracture is shown in Fig. 2. For the representative textile sample, a total of 11 images are recorded before the specimen broke. As shown in Fig. 3, there are two distinct sets of values - areas with von Mises strain values around 9 %, and around 22 % before break, with peak values around 24 %. Points 1 and 2 are placed in the central part of the specimen, in those distinct areas, with lower and higher strain values, respectively. Von Mises strain values in Points 1 and 2, before the break, are 11.4 % and 23.9 %, respectively, Fig. 3.

Diagram for Points 1 and 2 is shown in Fig. 3a, presenting the time dependence of the von Mises strain. Diagram for Section 1 is shown in Fig. 3b, presenting the length dependence of von Mises strain. Diagram in Fig. 3b shows material behaviour as heterogeneous, with von Mises strain values varying significantly, from 8 % to 24 %. The application of 2D-DIC, in this case, shows the significance of full-field analysis, as the conventional usage of the tensile test would have missed the difference in mechanical properties of the adjacent areas on the same specimen.

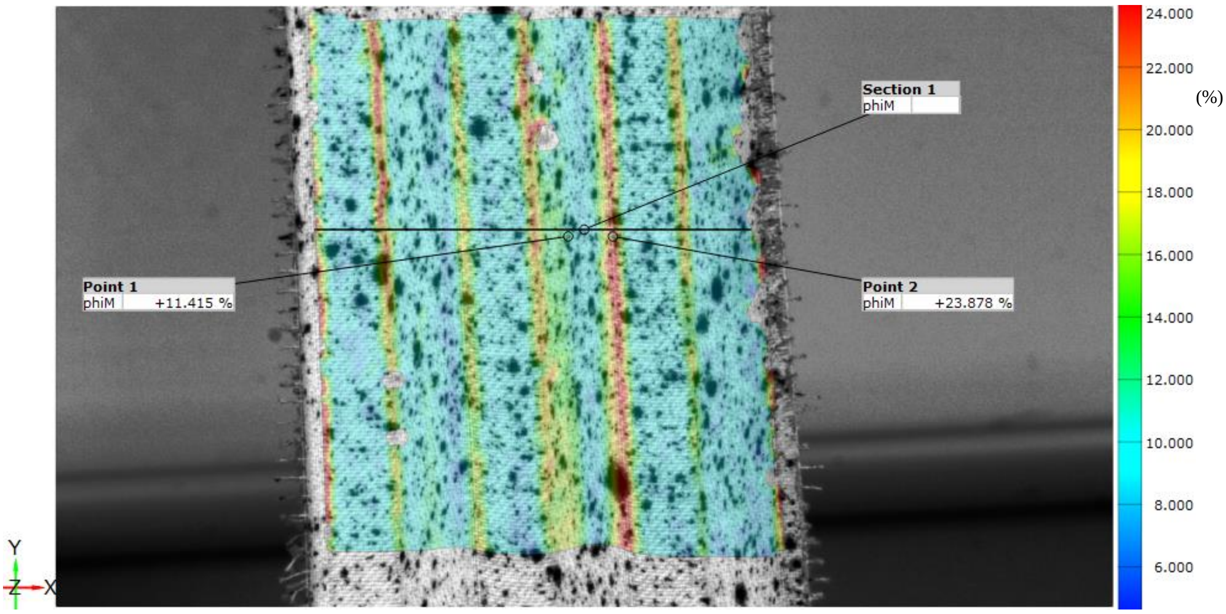

Figure 2. Representative von Mises strain field of the textile flat specimen.

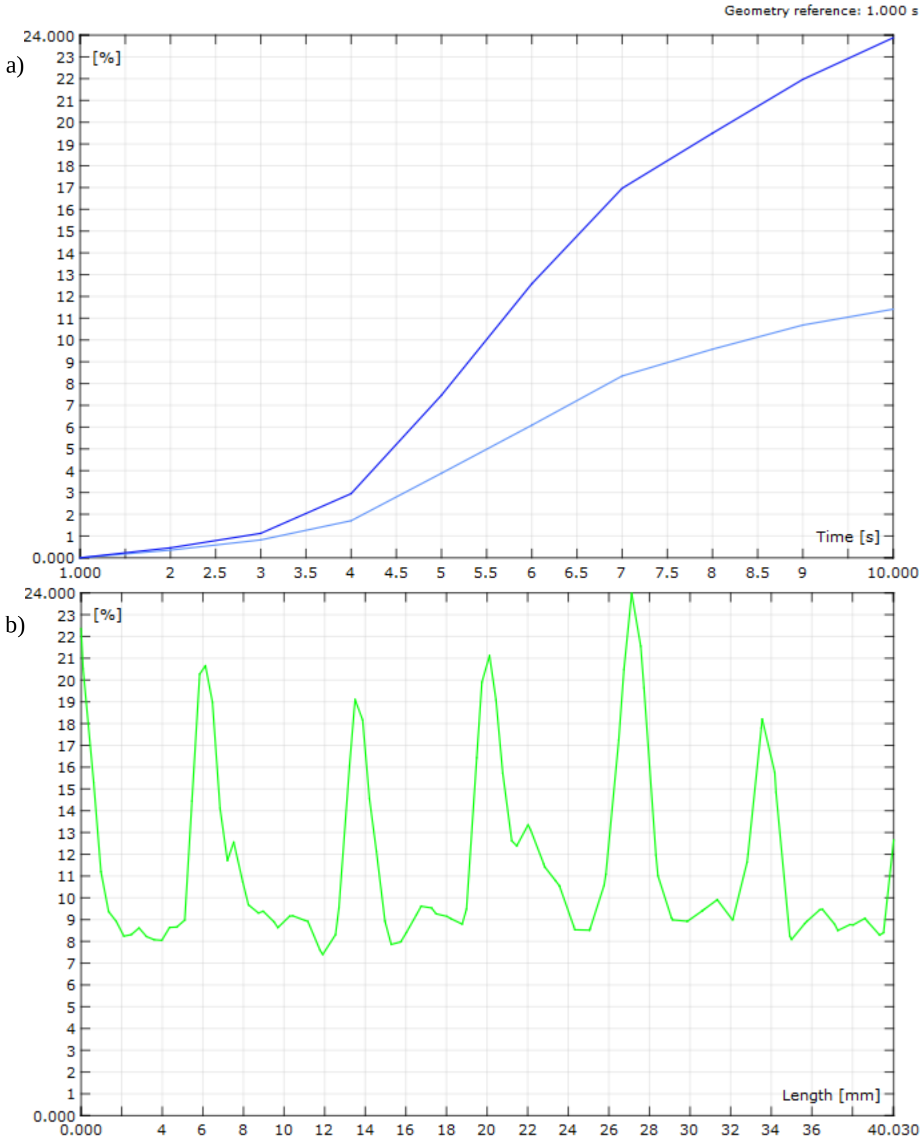

Figure 3. Von Mises strain diagrams: a) Stage points 1 and 2 strain values vs. time; b) Section 1 strain values for the final stage before the break vs. section length.

There are some peculiarities of textile materials that must be considered in textile-related standard tests for strength and durability, which are currently based on tests for solid materials. The main features of textiles are their discrete nature, large deformation, and lack of correspondence between macro and micro behaviour. The discrete nature of textiles makes it difficult to measure fabric dimensions for stress calculation, but it can be done by determining the fabric stress as force per yarn, or its strength in force per tex. The large deformation of textiles raises issues of nonlinearity and inter-yarn friction, and the lack of correspondence between macro- and micro behaviour presents a unique challenge for formulating a link between microstructural analysis and macroscopic performance.

One of the key advantages of 2D-DIC is its high spatial resolution. Unlike traditional strain measurement techniques that rely on gauges or rosettes, 2D-DIC can measure strains at every pixel in the image, providing a more detailed and comprehensive view of the deformation behaviour of the specimen. This information is useful for characterizing the inhomogeneity and anisotropy of the material. Another advantage of 2D-DIC is its accuracy. Unlike traditional strain measurement techniques that are prone to gauge positioning errors or measurement drift, 2D-DIC is not influenced by these factors, providing accurate and repeatable results. Additionally, the use of high-resolution cameras and sophisticated software algorithms allows for the correction of lens distortion, improving the accuracy of the results. 2D-DIC also provides real-time data acquisition, making it possible to monitor the deformation behaviour of the specimen as it is being subjected to loading. Additionally, the ability to visualize the deformation in real-time provides valuable insight into the deformation mechanisms of the material.

CONCLUSION

The use of 2D-DIC for tensile testing of thin specimens provides several advantages over traditional strain measurement techniques. These include high spatial resolution, accuracy, real-time data acquisition, and the ability to visualize the deformation behaviour of the material. This technique enables real-time monitoring of the stress-strain response, which is useful for identifying the material's yield point, maximum stress, and ultimate tensile strength. These benefits make 2D-DIC a valuable tool for characterizing the mechanical properties of thin specimens, and for gaining a deeper understanding of the deformation mechanisms in materials.

ACKNOWLEDGEMENT

This research is supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia under Project 451-03-68/2022-14/200105.

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