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HIGHLIGHTING THE PRESENCE OF RESIDUAL STRESSES IN RING-SHAPED METALLIC TEST SAMPLES

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Abstract: *The existence of residual stresses in the case of parts made of metallic materials can negatively affect the maintenance over time of some dimensions of the parts in which such stresses are found. It has been found that there are several distinct methods of evaluating the magnitudes of residual stresses in parts made of metallic materials. A method was proposed based on ring-type test samples, on which parallel ridges were drawn along a radial direction. By measuring the distances between the ridges before and after machining a radial slot between the ridges, it becomes possible to obtain information on the existence, type, and magnitude of residual stresses in the test sample material. Some preliminary experimental research has proven the possibility of using such a method to highlight residual stresses.*

Key words: *residual stresses, classification, assessment, ring-type test sample, slot.*

1. INTRODUCTION

Residual stresses, also known as *internal stresses*, represent those stresses that exist in most materials and workpieces when they are not subject to any external force.

The presence of residual stresses can significantly influence the technological and operational characteristics of metallic materials.

Although there are residual stresses in most solid engineering components, due to the complexity of their nature, ignoring the possible existence of high residual stresses in the design and manufacturing process can lead to less favorable results for the objective pursued.

The most important negative effects of residual stresses are the modification of the shape and dimensions of the parts due to residual stresses generated by previous processing, by operating the parts, or during their storage.

However, residual stresses can occasionally be useful. For example, when there are compressive residual stresses, they can increase the endurance of the part or when, through their distribution, it increases the bearing capacity of the element of a structure.

Residual tensions can be classified according to: the causes that generate them; the volume of material in which it self-balances; their spatial orientation.

The origins of residual stresses can be grouped into three large categories, depending on their nature: they can be mechanical, thermal and metallurgical.

Another classification of residual stresses considers the volume of material in which it self-equilibrates.

Residual stresses can also be classified according to their spatial orientation.

In recent decades, experimental methods have been proposed to measure residual stresses in various parts. Depending on the effect they have on the tested parts, the techniques for investigating the presence and residual sizes are: destructive, semi-destructive, and non-destructive (Fig. 1).

Thus, through the patent [1], a method and a device were proposed based on the use of drilling and milling processes to determine the spatial state of residual stresses in a solid body.

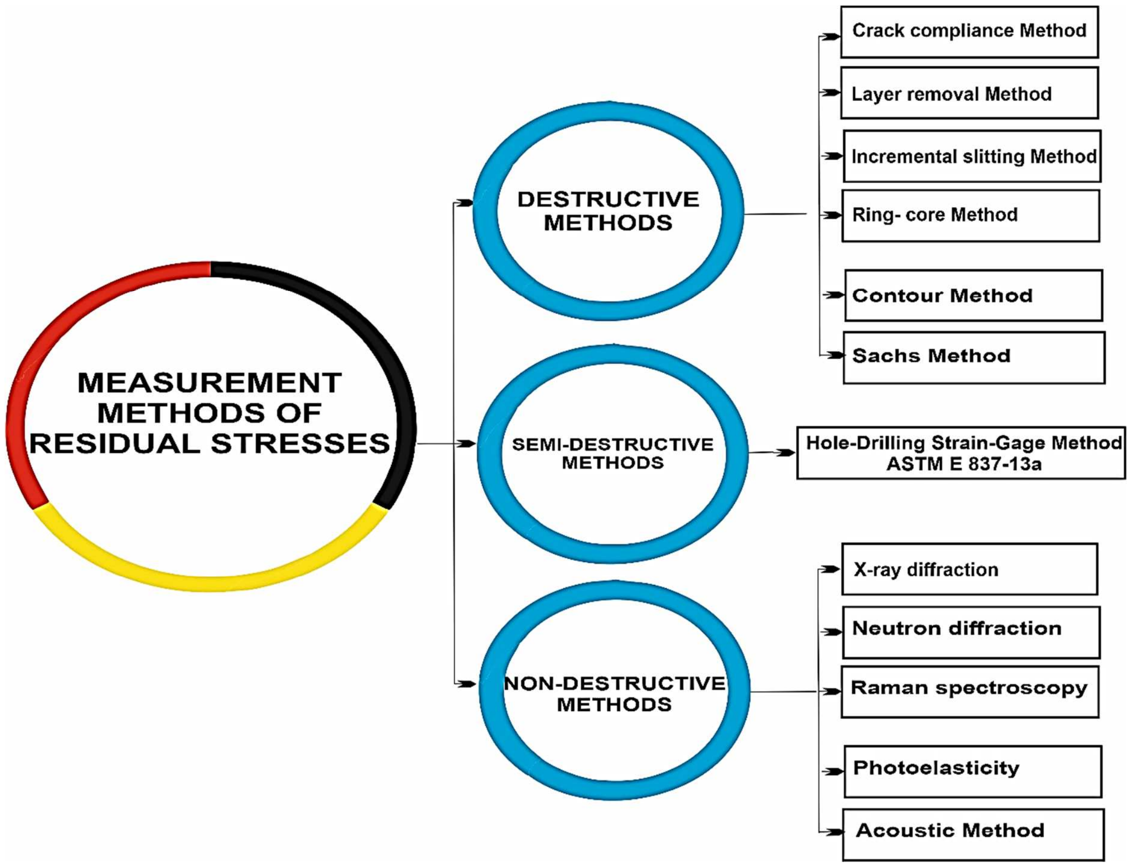


Fig. 1. Classification of methods for determining the magnitudes of residual stresses by taking into account the extent to which the sample's integrity is affected.

The so-called hole-drilling strain-gage method was applied to determine the in-plane residual stresses.

In another patent by the same author [2], a method and a tensometric element (resistive tensometric pin) are described for determining the spatial state of stresses in a solid body. The application of the method is carried out in several stages:

1. Gluing the hole-drilling rosettes comprising three single or pairs of strains gage grids, later connected to a strain gauge bridge;
2. Making a hole in the hole-drilling rosettes;
3. Mounting in the hole in the center of the rosette, with the help of a thin layer of adhesive, a tensometric element of the flattened resistive tensometric pin type.

Prevey and Cammet [3] patented a method of inducing residual compressive stresses in the surface layer of a part. Subsequently, the determination of the residual stress values takes place by using the diffraction effects of an X-ray beam.

Michael Prime [4] proposed a method initially used to determine the state of residual stresses in a section of a welded plate. Compared to other methods, the method proposed by Prime is relatively simple and cheap, and the necessary equipment is easily accessible.

With the help of the method proposed by Prime, the plane state of residual stresses is determined by using the inverse numerical method. Thus, it is used to measure the deformations of the resulting surfaces after sectioning the part.

A modeling by the finite element method then allows the identification of the magnitudes of the residual stresses that produce the deformations of the sample.

Viertl and Marshall [5] considered the possibilities of determining the plane state of residual stresses.

The proposed method considers the use of a strain gauge rosette. A particular aspect of the method is that of using a laser beam heating of an area of the sample. The method is semi-destructive, as the melted region is restored with

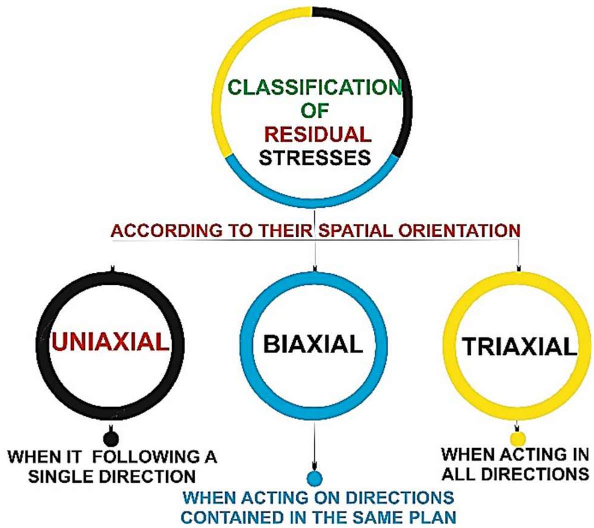


Fig. 2. Classification of residual stress determination methods by considering the spatial arrangement of stresses.

little loss of material. Other advantages of the method derive from the short duration of the application and from the possibilities of use in the case of samples with complex geometries.

Bekir et al. [6] proposed a technique for modeling the residual stresses during laser cutting by using a numerical discretization method when modeling the temperature variation and the residual stresses in the material of a sample, the residual stresses being generated by making some holes with a laser beam of small diameter.

In the paper [7], an electrochemical cutting device was presented. It started from the premise of using the device to highlight the magnitudes of residual stresses in ring-type parts.

The device can make a radial slot in a ring-type piece of steel difficult to cut by conventional machining processes. The sample material could be hardened tool carbon steel or high-alloyed hardened steel.

An evaluation of different residual stress measurement methods was performed by Guo et al. [8].

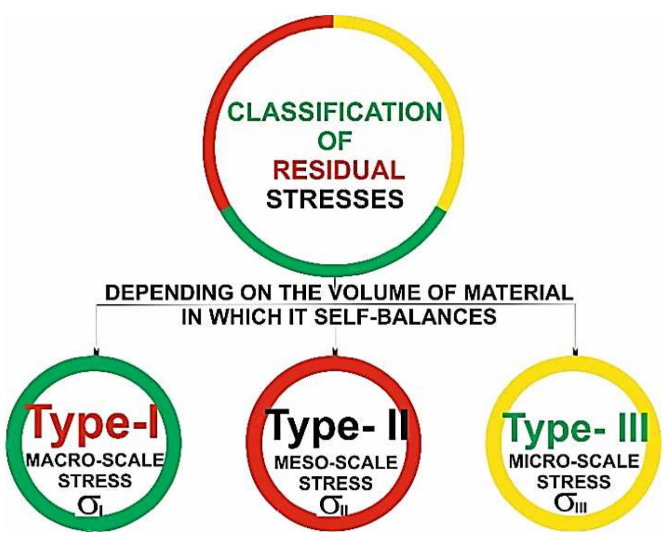


Fig. 3. Classification of residual stresses by considering the size of the space in which they manifest.

The authors also highlighted the problems and difficulties of different residual stress measurement methods.

The present paper aimed to identify a relatively simple solution for highlighting residual stresses generated by thermal treatments previously applied to some samples from materials difficult to cut by conventional machining processes.

Another classification of residual stresses is based on the spatial level at which they manifest.

There are, thus, *uniaxial residual stresses*, *biaxial residual stresses* (with manifestation in one plane), and *triaxial residual stresses* (Fig. 2).

Residual stresses can also be classified by considering the sizes of the areas in which they manifest.

In this way, residual stresses can be observed when they manifest at the macroscopic level, at the microscopic level, and, respectively, at the ultramicroscopic level (Fig. 3).

In the paper, the authors presented a method for highlighting the presence of residual stresses in the ring or disc-type parts based on drawing parallel lines and following what happens to the distance between the lines after executing a radial slot in the test sample under investigation.

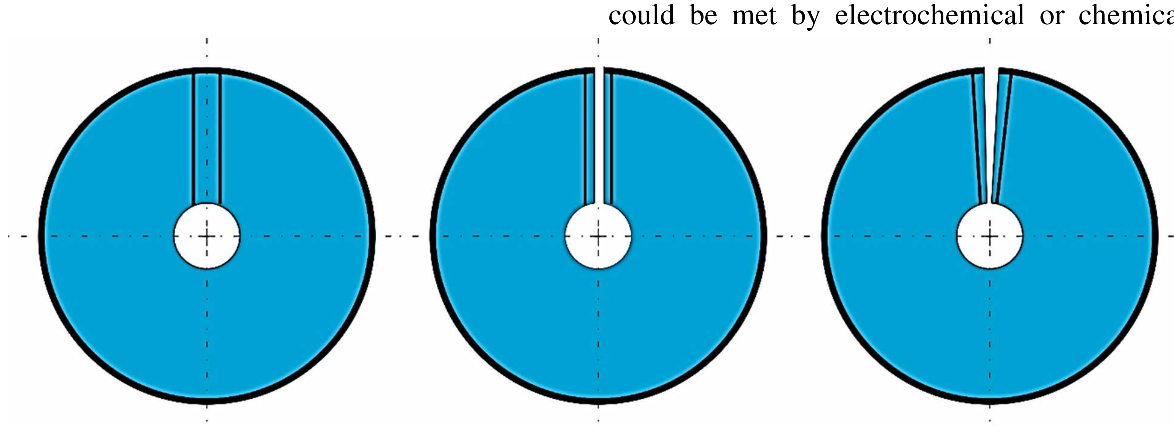
2. THE PROPOSED SOLUTION FOR THE HIGHLIGHTING THE EXISTING RESIDUAL STRESSES IN METALLIC PARTS

The research, the results of which are presented in this paper, was aimed to highlight and possibly evaluate the magnitudes of the residual stresses generated by previously applied thermal treatments by using a relatively simple practical method. The starting work scheme was based on using a ring-type specimen, as seen in Fig. 4.

The use of a hard steel test sample was considered (such as hardened tool carbon steel), previously subjected to hardening and tempering heat treatment. It is assumed that through the previously applied hardening and tempering heat treatment to increase wear resistance during tool use, an increase in hardness will be obtained first. Still, a result of the heat treatment could also be the appearance of residual stresses.

To obtain information on the magnitudes of these residual stresses, one could draw, on one of the flat surfaces of the ring-type specimen, two parallel ridges with a radial direction. The distance between the two ridges can be a few millimeters.

With the help of a precise measuring apparatus, it is possible to measure the distance between the axes of the two ridges. In the next step, with the help of a sufficiently thin abrasive disc, a radial slot will be made in the space between the ridges. The slot can also be made using an unconventional processing method (EDM cutting, laser beam cutting, etc.). Of course, the most convenient solution would be a slot-cutting solution that does not generate additional residual stresses. Such a requirement could be met by electrochemical or chemical



1. Drawing the ridges on the radial direction **2.** Making the slot **3.** Measuring the width between the 2 ridges after making the slot

Fig. 4. Highlighting the existence of residual stresses in a ring type test sample by cutting the ring.

cutting, but this would require specialized equipment.

Afterward, the distance between the previously drawn parallel ridges could be measured again using an apparatus with high accuracy in measuring linear dimensions. Suppose there will be differences between the dimensions measured before making the slot and, respectively, those measured after making the slot. In that case, it is expected that those differences can be justified primarily by the effects of the existence of residual stresses in the material of the ring-type test sample.

To the extent that the differences between the distances between the ridges before and after making the slot are positive, it can be stated that they are mainly the result of tangential compression stresses, while otherwise (the smaller distance between the ridges after making the slot to the one before the generation of the slot), it can be considered that the existence of tangential tensile stresses generated them.

The greater the differences between the parallel ridges before the slot is made and, respectively, after the slot is made, the more likely the residual stresses in the test sample will be higher.

To obtain more complete information on the magnitudes of the stresses in the ring-type test sample, it would be necessary to identify a solution by which, by applying forces of known magnitudes, the specimen can be elastically deformed, so that the distance between the ridges reaches the appropriate values to the situation before the slot was made.

3. PRELIMINARY EXPERIMENTAL TESTS

To carry out some preliminary experimental tests to verify the extent to which the assumptions entered in chapter 2 of the paper are valid, some preliminary experimental tests were carried out.

Thus, axial bearing ring type test samples were used. The axial bearing ring were made of hardened tool carbon steel 100C6, having a hardness of 53 HRC. The test sample had an outer diameter of 52 mm, an axial hole with a diameter of 35 mm and a thickness of 3 mm. With the help of a drawing needle with the active area made of sintered carbides, parallel lines were drawn on the axial bearing ring test samples, at distances of about 3 mm. Later, with the help of a device adapted to a universal lathe, radial slits were made in the ring-type test samples previously prepared.

The slots' actual generation was possible with an abrasive disc's help. Before making the slot and after making it, a measurement of the distance between the ridges was resorted to with the help of a digital microscope TM-1005B (this allows measurements with an accuracy of one micrometer).

An image of the scratches before and after making the slit in a test sample is the one in figure 5. Analyzing the distance between the lines drawn before and after making the slot by cutting with an abrasive disc, an increase in this distance is found (3,781 mm before making the slot and 3,801 mm after making the slot), it can be concluded that there are tangential compressive stresses inside the test sample.

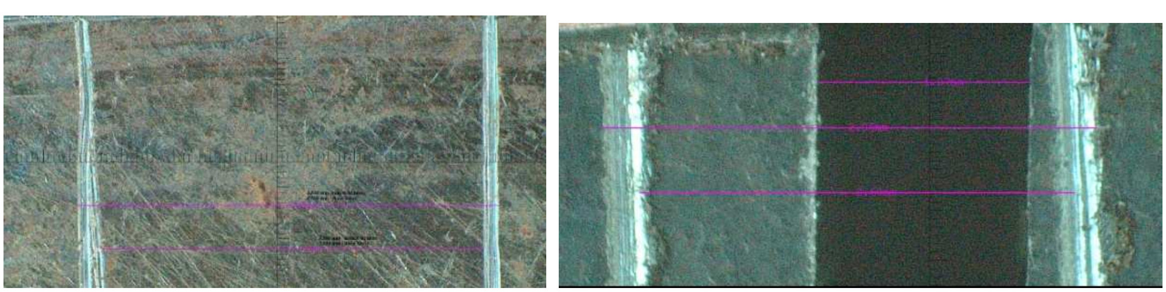


Fig. 5. Images observed under a microscope in the area under examination, before and after making the slot (test sample: axial bearing ring, material: 100Cr6, 55 HRC).

4. USING THE FINITE ELEMENT METHOD FOR MODELING THE BEHAVIOR OF THE TEST SAMPLE

The authors aimed to address how residual stresses can impact metallic test samples. The mechanical properties of the material 1.1520, which is the DIN equivalent of the tool steel C70U were used [9].

A new material was designed in engineering data based on structural steel that received the mechanical properties of DIN 1.1520. The 3D model has the same dimensions as the original test sample, with lines drawn 3mm apart. From the mesh point of view, it was introduced a patch compliance method and used an element size of 0.25 mm.

This resulted in the generation of 155417 elements which produced a fine mesh. As a result, a variation of 0.062387 mm was obtained for the total deformation, as can be seen in figure 6.

This takes into account deformation on all three axes which considers also reorganization of internal molecules after cutting.

The FEM confirms that due to the residual stresses, a small deformation occurs when the slot is made in the test sample, but the slot width is very small, due to the strength of the material and the dimensions of the test sample used. The equivalent Von-Mises stress is manifested on the two faces who are formed after cutting, as well as at the level of the hole in the specimen.

Further refinements could reveal more information on fatigue life and safety factors as a stress-related tool.

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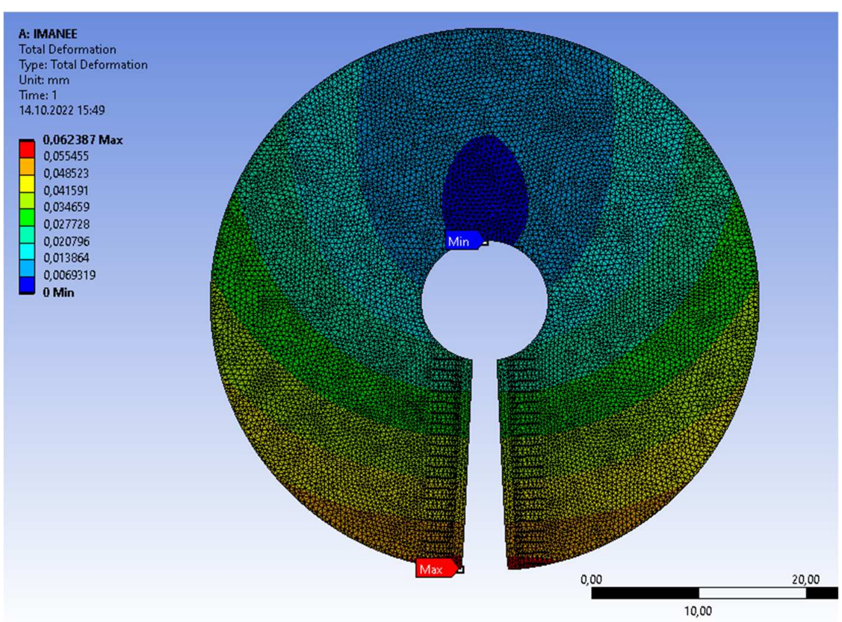

Fig. 6. Distribution of Total Deformation contour bands over the entire surface of the analyzed part (magnified view 28 times).

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The equivalent Von-Mises stress is manifested on the two faces who are formed after cutting, as well as at the level of the hole in the specimen. Further refinements could reveal more information on fatigue life and safety factors as a stress-related tool.

5. CONCLUSIONS

In the last decade, the dynamics of the development of methods for determining the existence and sizes of residual stresses in hard and extra-hard materials has highlighted research directions such as the extension of experimental research to determine residual stresses on other categories of materials than those studied so far, the use in the framework of the theoretical and experimental modeling of the finite element method, the existence of continuous concern for the improvement of existing methods and related equipment, including by proposing and materializing methods and equipment with a high level of technicality.

In the paper, the hypothesis of the possibility of highlighting the presence of residual stresses by using a ring-type test sample was formulated.

By measuring the distance between two parallel ridges before and after making a radial slot in the ring-type test sample, some information can be obtained regarding the existence and magnitudes of residual tangential stresses in the material of the test sample.

Some preliminary tests confirmed the possibilities of developing and investigating such a method.

In the future, the design and materialization of some experimental plans that allow highlighting the influence and the weight of the influences exerted by some dimensions of the sample, by the hardness of its material, etc., on the magnitudes of the residual stresses are considered.

The research will also aim to identify possibilities for evaluating the magnitudes of the stresses in the test sample and correlating the magnitudes of the stresses with the change in the distance between the parallel lines drawn on the test samples.

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Evidențierea prezenței tensiunilor reziduale în epruvete metalice sub formă de inel

Existența unor tensiuni reziduale în cazul pieselor din materiale metalice poate afecta negativ menținerea în timp a unor dimensiuni ale pieselor în care se regăsesc asemenea tensiuni. S-a constatat că există mai multe metode distincte de evaluare a mărimilor tensiunilor interne din piesele realizate din materiale metalice. A fost propusă o metodă ce se bazează pe utilizarea unor epruvete de forma unor rondele, pe care au fost trasate rizuri paralele în lungul unei direcții radiale. Prin măsurarea distanțelor dintre rizuri înainte și după realizarea prin prelucrare a unei fante radiale între rizuri, devine posibilă obținerea unor informații privind existența, tipul și mărimea tensiunilor reziduale din materialul epruvetei. Unele cercetări experimentale preliminare au probat posibilitatea folosirii unei asemenea metode de punere în evidență a tensiunilor reziduale.

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