

Comparison of Ring-Core Method and Hole-drilling Method Used for Determining Residual Stresses

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Abstract Ring-Core method is derived from a hole-drilling method and both are used for determining uniform and non-uniform stress through the thickness of specimen. The reason for creation the Ring-Core method was to remove some of the shortcomings of hole-drilling method. Both methods are semi-destructive methods, because they both partially destroy the studied specimens which are subsequently easy to fix and thus they are still useful. The aim of this article is to compare these two methods and thus help experimentalist to choose the appropriate method for determining residual stresses. Because Ring-Core method is less common, we will discuss more about this method in the article.

Keywords: residual stresses, Ring-Core method, hole-drilling method

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1. Introduction

The residual stresses [4] are the stresses that exist in objects without external loading. These stresses are generated by technological processes or by previous loading. In principle all technological processes – rolling, forming and thermal processing etc. generate in produced objects residual stresses. The residual stresses play the same role in the strength of a structure that common mechanical stresses do, but while the stress due to external loads can be calculated with a certain accuracy, the residual stresses are difficult to foresee, and therefore it is very important to have a reliable method allowing to measure them directly in the structure with a minimum damage for it.

The Ring-Core and the hole-drilling methods are semi-destructive methods used to quantify the principal residual stresses within a specified depth of material. Both techniques are relatively rapid and convenient in practice. The specimen is not totally destroyed during measurement and in many cases could be used for another application.

2. Hole-drilling Method

The most widely used semi-destructive technique for measuring residual stress is hole-drilling method Figure 1. The foregoing procedure is relatively simple, and has been standardized in ASTM Standard Test Method E 837 [1]. The principle of this method lies in the application of the strain gage rosette on the top of the part being examined and consecutive drilling of a hole in a center of the rosette. This procedure disrupts the internal force and moment

equilibrium and causes distortions nearby the drilled hole, which are measured by the strain gage rosette. The measured strains are evaluated and using derived theory course and magnitude of residual stresses are determined. This method is considered to be semi-destructive because the drilled hole (diameter 2-4 mm to a depth of 2-4 mm) is insignificant and can be easily corrected, for example by inserting a screw, pin or welding etc.. Small surface disturbance does not affect the functionality of the components. Theory of the hole-drilling method is based on a solution of plate with a through hole. For determining residual stresses by the hole-drilling method for example System SINT - MTS 3000 can be used, representing progress in determining of the residual stress by the hole-drilling method Figure 2 [6,8].

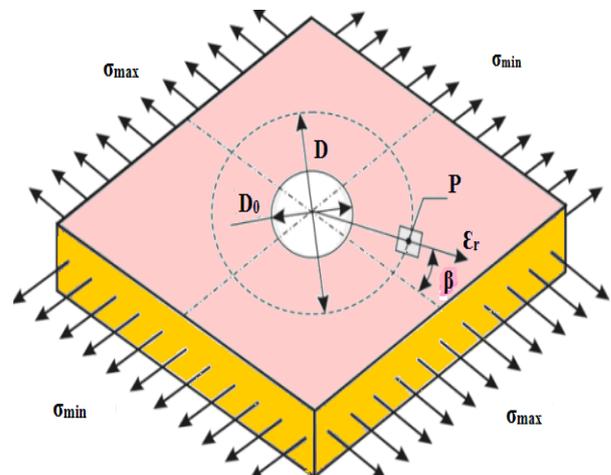


Figure 1. Principle of the hole-drilling method

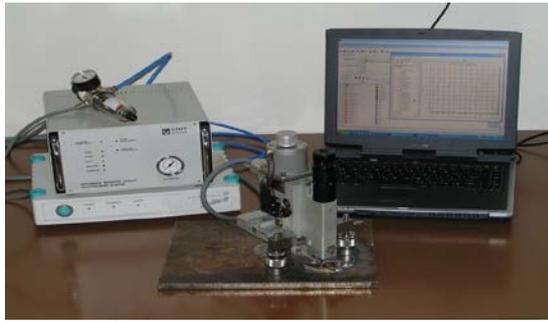


Figure 2. System SINT-MTS 3000

3. Ring-Core Method

The Ring-Core method is undoubtedly less common than the hole-drilling method. In addition of being more “destructive”, the fact that actual performance of the test is more complex has limited evolution of the method. It has considerable similarities to the hole-drilling method, in fact, the two methods are complementary as they are based on the same mathematical equations for calculating residual stresses from measured strains, although the methods clearly have totally different calibration constants and curves.

Ring-Core method can be used for determining uniform and non-uniform residual stresses. The principles of this method are based on the hole-drilling method, but instead of drilling a hole through the middle of strain gage rosette, a notch is milled around the rosette [2,3], which has dimensions about: $D= 18\text{mm}$, $d= 14\text{mm}$, $h= 4$ to 5mm Figure 3. This implies that Ring-Core method is more destructive than a hole-drilling method but is still a semi-destructive one.

Small annular groove in the surface of the specimen is milled concentrically around a strain gage rosette, leaving the upper part of the core separated from the surrounding material. This separation causes the relaxation of the residual stresses presented in core, which is represented by deformation of the core. These deformations can be measured by strain gages designed for measuring relieved strains by the Ring-Core method. The annular groove can be machined with suitable cutter, like a ring saw.

This method is less sensitive to errors involved in positioning of the cutting tool relative to the strain gage and stress can be measured more accurate up to the yield stress of material.

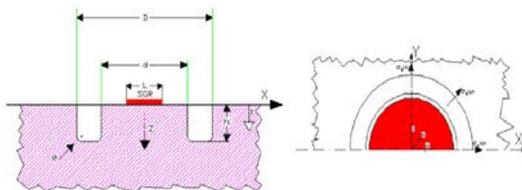


Figure 3. Ring-Core method

Milling is made for selected steps and at each step measured values are recorded. The process is repeated, usually to a depth of 4 mm. The obtained data are processed in a suitable evaluation procedure (eg Integral method, Incremental method etc.). Ring-core method allows to measure in greater depths by removing the milled ring. Subsequently new strain gage rosette is bonded to the surface and new ring is milled. This may continue up to the depth of 25 mm.

Assumptions, limitations and applicability of Ring-Core methods:

- Residual stresses in the direction perpendicular to the surface of the material are neglected.
- Residual stresses are constant throughout the depth or milling steps.
- In milling process it is not allowed to bring further residual stresses to the investigated material.
- The material has a homogeneous structure and it is linear elastic.
- Unloaded material surface (the surface tension of planar arises).
- The surface of the examine material is planar.

Influencing factors:

- Dimensions of the specimen are large enough that the thickness of the material allows the creation of a blind groove.
- Measuring point shall be located at a sufficient distance from the geometric characteristics (adjacent holes, radius).
- Center location of the strain gage rosette has to be the geometric center of the groove.
- Cylindricity and perpendicularity of the core with respect to the plane of the surface
- Type of the strain gage rosette - geometry and size of the strain gage measuring grids.
- The type of method, which is used for evaluating the residual stresses.

Basic steps for the determining residual stresses by the Ring-Core method:

- Apply a strain gage rosette with three overlapped grids in the test area (prepare surface, bond and solder leads).
- Protect the strain gage rosette and leads.
- Place the mechanical section of the instrument on the desired area.
- Center the crown milling cutter and strain gage rosette.
- Set a zero depth.
- An annular groove is machined around the strain gage rosette in depth increments, and at each step the strain values are measured by the three grids.
- The previous step is repeated to reach a minimum depth of 4 mm.
- The acquired strains are processed by the most appropriate method [4].

An example of the system used to determining residual stresses by the Ring-Core method is System MTS3000 Ring-Core Figure 4.



Figure 4. System SINT MTS 3000 Ring-Core

4. Comparison Between the Ring-Core Method and the Hole-drilling Method

The Ring-Core method is younger, but in terms of theoretical and practical application is similar to the hole-

drilling method. The basic difference between these two methods is shown in Figure 5. In first case, we drill hole through the center of the strain gage rosette and in the second case we made annular groove around the bonded strain gage rosette.

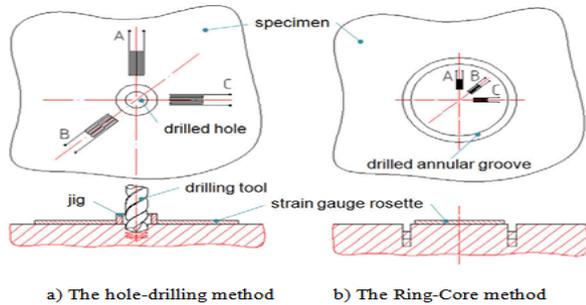


Figure 5. Difference between semi-destructive methods

The Ring-Core method is more sensitive in comparison to the hole-drilling method because it involves almost complete relief of the surface strains. However, the size of annular groove is relatively large, causing much more damage than the hole-drilling method, which allows more localized residual stress measurement. Despite its potential disadvantages, the hole-drilling method is the most common choice. Method is well established, experimentally and theoretically.

Difference between these two methods is also in used strain gage rosette. These methods are usually used to measure the residual stresses in metals, but they are also useful for other materials, for example ceramics, polymers, etc [7].

The following tables (Table 1, Table 2, Table 3, Table 4) summarized the fundamental differences between the Ring-Core method and the hole-drilling method.

Table 1. Comparison of the Ring-Core method and the hole drilling method (general characteristic)

Characterization	Ring-Core method	Hole-drilling method
Age	Younger, cca 1950	Older, cca. 1930
Signal transmission	Through lead connected to strain gage rosette through hollow milling cutter	Through lead connected to strain gage rosette besides mechanical unit
Strain gage rosette	For example. HBM K-RY 51/350	For example. HBM RY61-1,5/120

Table 2. For uniform residual stresses

Characterization	Ring-Core method	Hole-drilling method
Highest sensitivity	For determining residual stresses it is enough to measure only in 2 different depths	Drilling to depth 0.8 multiple of middle diameter of strain gage rosette

Table 3. For non-uniform residual stresses

Characterization	Ring-Core method	Hole-drilling method
Highest sensitivity	5 mm for common measurement Special case of measurement up to 25 mm	0.3 - 0.4 multiple of middle radius of strain gage rosette

Table 4. Comparison of sensitivity, measurability and influence of temperature

Characterization	Ring-Core method	Hole-drilling method
Sensitivity on hole eccentricity	less sensitive on errors caused by inaccurate location of mill due to the middle of strain gage rosette	more sensitive on errors caused by inaccurate location of drill due to the middle of strain gage rosette
Measurability of residual stresses	up to the yield stress	up to the 0.6 multiple of the yield stress
Influence of temperature	Less sensitive on temperature	More sensitive on temperature

Advantages of the Ring-Core method:

- Possibility to measure residual stress in greater depths.
- It is suitable for measuring coarse-grained materials.
- Less sensitive to errors caused by inaccurate location of the milling tool with regard to the middle of strain gage rosette.
- Measurement is possible up to the size of the yield stress of the material.
- In the process of milling introduced additional residual stresses have no such a great influence on the measurement of residual stresses than in hole-drilling method.
- The measured signal is at least larger than in hole-drilling method.

Disadvantages of the Ring-Core method:

- Need of determination of the calibration coefficients depending on the mechanical properties of the material, geometry of milled core, total depth of the ring, type of strain gage rosette.
- Ring-Core method is not standardized unlike the hole-drilling method.
- Limitations on applicability of the method and the need to respect the factors affecting accuracy.
- Long process of measurement.

4.1. Strain Gage Rosettes Used for Residual Stresses Measurements

In hole-drilling and Ring-Core method different types of strain gage rosettes are used. Comparing these two

methods it is obvious that in hole-drilling method we drill to the middle of strain gage rosette while in Ring-Core method we mill around the strain gage rosette. Company producing strain gage rosettes is for example Hottinger Baldwin Messtechnik GmbH (HBM), which produces strain gage rosettes for both methods. Different types used in these methods from the company HBM are shown and described in the next section [9].

Strain gage rosettes used for Ring-Core method

Figure 6:

XY 51:

- We use this strain gage rosette when we know direction of principal stresses.
- Dimensions: $a = 5 \text{ mm}$, $b = 2.5 \text{ mm}$, $c = 12 \text{ mm}$, resistance 350Ω

RY 51:

- We use this strain gage rosette when we do not know direction of principal stresses.
- Dimensions: $a = 5 \text{ mm}$, $b = 2.5 \text{ mm}$, $c = 12 \text{ mm}$, resistance 350Ω

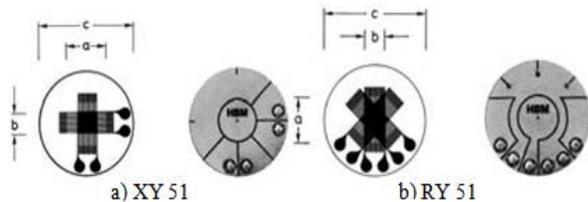


Figure 6. Strain gage rosettes used for Ring-Core method

Strain gage rosettes used for hole-drilling method:

For hole-drilling method we can use three basic types of strain gage rosettes defined by ASTM E 837 [9].

Type A:

- Strain gage rosette for general using, for example. RY61 made by HBM (Figure 7 a)
- Dimensions: $a = 1.5 \text{ mm}$, $b = 0.8 \text{ mm}$, $d = 12 \text{ mm}$, resistance 120Ω

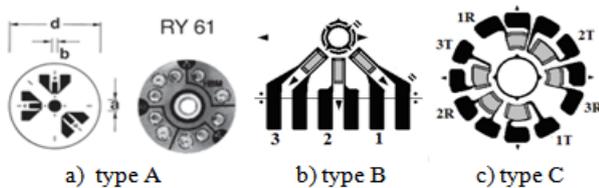


Figure 7. Strain gages for the hole-drilling method

Type B:

- Has all grids placed in one direction (Figure 7 b).
- We use this strain gage rosette for drilling near obstacle.

Type C:

- For measuring strain with high sensitivity and in cases when we need high temperature stability (Figure 7 c).
- Has three pairs of grids placed opposite each other which are connected to half bridge circuits.

5. Conclusion

In this paper we briefly mentioned the possibility of determining residual stresses by semi-destructive methods, especially by using hole-drilling method and Ring-Core method. This short summary of findings may help experimentator to correctly decide which of these two methods is in his case more appropriate.

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