The 17th INTERNATIONAL DAAAM SYMPOSIUM
"Intelligent Manufacturing & Automation: Focus on Mechatronics & Robotics"
8-11th November 2006

ECONOMICAL DETERMINATION OF RESIDUAL STRESSES IN CASTINGS

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Abstracts: *After complete cooling off of the castings, residual stresses occur. If stresses exceed tensile strength of the component in production or service, deformation or cracking of the casting will happen. To avoid casting defects, it is necessary to know how big the residual stresses are and if they surpass the allowed values. The paper's presented some of the methods for measurement of residual stresses by DMD 20 and MTS 300 device, and has given comparative analysis of their cost effectiveness.*
Key words*: Residual stresses in castings, determination of residual stresses, DMD 20, MTS 3000.*

1. INTRODUCTION

Residual stresses are those stresses which exist in some machine member, also when there are no external loadings or temperature gradients. Production processes favor by and large creation of residual stresses (for example casting, welding, machining, heat treatment) by capturing residual stresses within the work piece (Heidl & Husnjak, 1987).

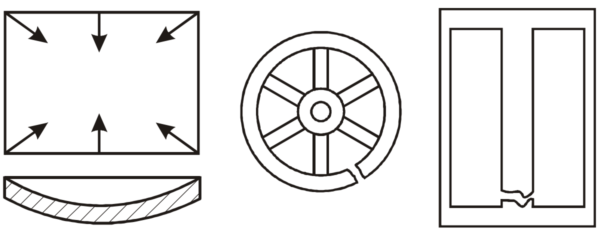
After complete cooling off of the casting there are residual stresses which equal sum of stresses having different origin. If these stresses exceed tensile strength of the machine member, cracking and distortions of the casting in production or service will take place.

2. CASTING DEFECTS

Some typical casting defects caused by great residual stresses are shown in Fig. 1. (Atlas of Casting Defects, 1965). Fig. 1.a shows gray casting distortion due to unsymmetrical allocation of stresses, as consequence of unequal cooling off of the plate, while Fig. 1.b discloses casting cracks which occurred in warm or cold condition. Hot cracks occur at high temperatures on crystal boundaries. Primary cause for occurrence of hot cracks is first and foremost resistance to changes of volume (resistance to free shrinkage). Cold cracks take place at lower temperatures and due to exposure to loading during operation.

3. DETERMINATION OF RESIDUAL STRESSES

In practice we frequently face the task how to determine size of the residual stresses in the castings. Complexity of constructions, and many influential and relevant parameters quick solution of this theoretical problem, applicable to foundry practice, cannot be expected.



a b

Fig. 1. Casting defects caused by residual stresses

Therefore methods for determination of residual stresses during inspection and manufacturing process of castings are being invented, which are not sufficiently reliable, and what's most important, lack simplicity and cost effectivness. Dependable determination of residual stresses requires measurements on construction itself. It cannot be accomplished on models, because models can only add qualitative impression about allocation of these stresses. That's why measurement devices must be simple so as to be able to apply them on site, frequently on inaccessible parts of the construction. Methods of measurement must eliminate influences arising from change of temperature, humidity and similar influences. Measurements during manufacturing process, when residual stresses come into being, are on the whole impossible due to high temperatures, enormous plastic deformations and similar (Heidl & Husnjak, 1987).

Technically applicable and practically appropriate methods for determination of residual stresses can be classified, according to degree of damage to construction member / casting, into:

- Non-destructive methods of measurement
- Partially destructive methods
- Destructive methods

With non-destructive methods of measurement casting is not damaged. Partially destructive methods can be reduced to non-destructive methods, because areas of damage of the casting are very small. With castings these areas of destruction can be tailored by additions for machining of the section, subsequent machining practically removing damaged areas.

Two most applied methods of partly destructive measurement are cutting of circular groove and hole drilling. Method of cutting of the circular groove is used so as to cut out of a groove around the measuring point, which leads to relaxation of the stresses in the area of the work piece surrounded by the groove. The rest of the core is extracted from equilibrium of forces and moments, easing thus internally available stresses. Thus distortion of component of the work piece is being effected, which is then measured by application of mechanical, electrical resistance-based or photo elastic tension meters. To determine completely state of stress on the surface of the work piece, distortions in at least three directions must be measured.

Hole drilling method is very suitable because it can be applied on large pieces, without destruction of the piece itself. Hole diameters range from 1, 5 to 1, 8 mm, with depth up to 4 mm. Residual stresses around the hole are thus partially relaxed. The accompanying distortions can be measured and be used for determination of residual stresses. Distortions are most frequently measured by tension meters installed at equidistance from the center of the hole.

Destructive methods of measurement are those which totally destroy casting. These methods are also called relaxation methods, because they are associated with cutting and relaxation.

In foundry practice technological probes designed to cause intentional stresses in castings are being used recurrently. There are two such technological probes:

- Grid like
- According to Thomas

Both of these technological probes are designed so as to contain thin and massive profile, which leads to creation of stress during cooling off, due to their mutual resistance to shrinkage. Stress measurement on probes is carried out so as to measure distances of exactly defined positions prior to cutting and after cutting.

4. MEASUREMENT OF RESIDUAL STRESSES ON GRID LIKE PROBE

Technological probes of certain dimensions made of gray casting have been manufactured. After cooling of the casting preparation of measuring points and gluing of measuring tapes in accordance with HBM Instructions (Hottinger Baldwin Masstechnik) (Hoffmann, 1996) has been effected. For determination of residual stresses devices of the company HBM have been used. Measurements on grid like probes have been carried out:

- DMD device for destructive/relaxing method of measurement
- MTS 3000 device for partially destructive hole drilling method of measurement

4.1 Measurement of Residual Stresses with DMD 20 Device

Principle of measurement with DMD 20 is to enable creation of the full Wheatston bridge. Procedure of establishing of the full bridge is enabled in such a way that 3 compensation tapes are glued on 50x50 mm plate made out of the same material as the casting, and 4 active tapes on the casting on which stress is being measured. Prior to measurement itself nullifying of device, calibration and feeding in of the k-factor tape coefficient is carried out. Measurement is conducted so that cables are connected from measuring tapes to device and the real value ε_1 is read out. After that the object is cut through and left for at least two hours prior to second measurements. After that the second value ε_2 is read out. The measured distortion value is:

$$\varepsilon = \varepsilon_2 - \varepsilon_1 \ (\mu m/m) \quad (1)$$

Internal stress is calculated by the equation:

$$\sigma = E \cdot \varepsilon \ (N/mm^2) \quad (2)$$

E – Modulus of Elasticity N/mm^2

Measurement of grid like probe by DMD 20 is shown in Fig. 2.

4.2 Measurement of Residual Stresses by MTS 3000 Device

MTS 3000 device is used for measurement of residual stresses by hole drilling method of measurement. It uses HBM measuring technology. To enable measurement compressed air must be provided for (for example: compressor).

The required pressure is 4 bars, which represents optimal incoming value for air necessary for putting into motion of the turbine within device. Air is introduced through valves and filters into control device for further connection with the hole drilling device. Measuring cables from rosette are jointed onto control device directly or over signal intensifier.

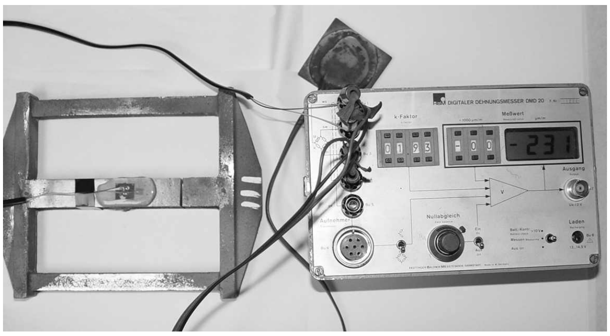


Fig. 2. Determination of Residual Stresses with DMD 20

Fig. 3. Grid like Probe Measurement

If connection is effected without signal intensifier, PC or laptop must have a card for signal intensification (i.e. I/O card PCI 6023E or DAQCARD 6024 of the company National Instrument), so that this software implements residual stress measurement. In case that we use the signal intensifier, we don't need cards. The measurement process itself is carried out over computer.

Starting of the Restan program enables adjustments of measurement parameters in the main menu:

- Positioning of the Drill
- Setting of measurement parameters, drill diameter and number of steps.
- Sequencing of steps (lines or curvatures)
- Data on measuring tape/rosette and setting of its values on null (nullifying)
- Data on work piece being tested (Material, Modulus of Elasticity, Poisson's coefficient)
- Selection of the type of intensifier or measuring card
- Record of general measurement data (Date, operator's name, description of measurement …)

Preparation of measurement - prior to measurement it is necessary to determine drilling speed and the way how to read data. There are two ways how to do it: manual (step by step) or automatic. With manual method, the operator himself stops the device to read out measurement values for certain depth, while with automatic method device itself reads automatically data according to pre-given number of steps. After each step computer reads out distortion values and records them. After measurement data is recorded into software. There, on the basis of obtained results residual stresses are calculated by one of the methods (ASTM E 837-01, INTEGRAL, KOCKELMANN, POWER SERIES).

5. CONCLUSION

If residual stresses are greater then tensile strength they cause casting defects. To avoid defects, it is necessary to know the size of residual stresses, and if they exceed permissible stresses. Casting of probes and testing by destructive methods is suitable for research testing of i.e. influential stress parameters.

Reliable determination of residual stresses demands measurement on construction itself, and cannot be effected on models, because such testing can only add qualitative impression on allocation of residual stresses.

Out of aforementioned it can be concluded that it is more economical to measure stresses on finished pieces, than to manufacture grid like probes.

6 LITERATURE

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