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Stress Determination Made Easy

While shot peening intensity verification is the well-established standard in shot peening quality control, the more relevant residual stress determination is mostly caught up in laboratories of a production plant or of external service providers. Until today, the related measurement procedures are complex and time consuming. Fast inspection methods for in line inspections are already available but limited to simple setups. With StressEasy, the new software extension to Pulstec's simple, fast and mobile µ-X360s stress analyzer, sentenso presents a new flexible software tool for the assistance and automation in multiple and complex measurement tasks.

Residual stress determination in the past was time consuming and complex to setup with the need for very precise positioning of the specimen and the need for a mechanically complex goniometer. Starting in the 1970s, Japanese scientists developed a new method to determine stress states in metallic materials using a two-dimensional area detector. The so-called cos-alpha method has several advantages over the standard X-ray diffraction methods. Instead of tilting the X-ray source and detector during the measurement, the method utilizes the complete Debye-Scherrer ring data that is collected on the area detector. Since the stress level can be determined from the ring shift on the detector, movements of X-ray tube and detector are not needed and the measurement time can be reduced to as low as 35 seconds on most ferritic steel samples. Texture and coarse grain conditions can be spotted from only one measurement. These advantages allow for fast, precise and reliable stress determination.

Figure 1: Stress measurement on a gear tooth

The µ-X360s introduced in 2012 by the Japanese Manufacturer Pulstec is utilizing the cos-alpha method to implement the aforementioned benefits into an affordable and fully mobile X-ray diffractometer using a high-resolution image plate (IP) as area detector. The µ-X360s provides fast and stable measurements as well as a lightweight, portable and robust design, while emitting extremely low dose rates. In combination with sentenso's new software extension, StressEasy, stress determination is highly automatized and easy to setup. StressEasy is connecting to the µ-X360s, runs in a web browser and provides the connection to a robot to automatically move the µ X360s sensor unit.

StressEasy provides the following functions:
- Stress limit checks
- Batch measurements
- Stress mappings
- Oscillation methods (linear, circular, ψ-angle)
- Out-of-plane shear stress determination
- Stress matrix determination

StressEasy will be constantly developed further to implement user ideas and additional functions.

Stress Limit Checks in Production

Measuring stress in a production line can be quite challenging due to the required cycle time. A simple and fast solution for inline check of residual stress levels has been presented earlier ("The Shot Peener Magazine", Vol 35, Issue 3, Summer 2021 and Vol 31, Issue 3, Summer 2017). That device, however, is not using an area detector and thus not collecting the complete Debye-Scherrer ring, so the accuracy is reduced. Specific measurement setups and configurations are very limited.

As an example, when stress limit checks would be useful imagine a diaphragm spring that is measured after shot peening. A failure-critical position is chosen to compare the actual value with limits set by engineering. In the software a minimum and maximum stress level expected in the respective measurement spot can be set. Exceeding these limits will cause the software extension StressEasy to give out a signal so further steps can be done—for example, sorting out the part for additional measurements.

Multiple Measurement Tasks

In order to save a lot of valuable operator time, StressEasy provides configurable batch measurement functions to set different measurement tasks and positions beforehand. The measurements are carried out in the order and amount set by the user automatically without the need for additional user input.

Stress Mapping On Critical Surface Areas

Often in stress analysis, not only a single spot on a surface has to be checked but a mapping of the stress distribution in a certain area is required.

Large scale mappings of the residual stress on a surface require a number of single measurements with the following properties:

- A fast measurement per position is needed since the amount of measurements rapidly grows with the area size.
- The measurements should be easy to setup and easy to configure.
- The measurements should be performed automatically without the need for user input once the measurement has started.

When designing a part and developing the processes needed to manufacture it, the outcome of the residual stress distribution can only be assumed. Instead of destructive cycle tests, stress mapping can be a powerful feature to develop process parameters to get the best possible outcome of residual stress. In Figure 2, an induction heated part is shown with a spot in the middle and around it the heat influenced zone. This 21x21 = 441 was done using the mapping feature of StressEasy. StressEasy is able to create mappings of up to 100 points in just one hour on ferritic steel when used with a robot. A mapping like this provides valuable information about the stress distribution in the part and helps optimizing the manufacturing processes.

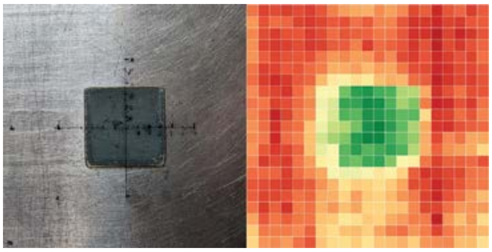

Figure 2: Stress mapping on induction heated part

Measurement Stabilization for Challenging Grain Structures

Even if uncommon with shot peened parts, the grain structure can be coarse—for example in weld beads and additively manufactured parts. Measuring parts under these conditions is challenging since the Debye-Scherrer ring used to determine the stress is missing information in certain areas over its circumference. With a coarse grain structure random grain orientations are missing and can't add a signal to the detector. This leads to a spotty Debye-Scherrer ring difficult to analyze.

To overcome this problem in X-ray stress analysis, oscillation methods are used to "fill the gaps" of the imperfect signal. The automatic oscillation functions of StressEasy provide various options to gather more grain information by either moving or tilting the sensor unit and thus stabilizing the measurement results.

Solution to Complex Stress States

The μ-X360s is determining residual stress by a two dimensional detector as discussed above, but is sensitive not only to the stress in measurement direction σx but also to the out-of-plane shear stress τxz. If τxz is not equal to zero multiple measurements from different measurement, directions are required. This can be easily achieved by rotating the sample or the sensor around the sample surface normal ($\phi 0$).

To determine stress under out-of-plane shear stress conditions, it is sufficient to rotate by 180° and then calculate the mean value of both measurements. If the complete stress matrix (stress tensor) is needed there are several options to perform this measurement. Assuming a stress-free condition in sample normal direction (σz), rotating the sample around $\phi 0$ in 90° steps the residual stress can be calculated from the gathered data.

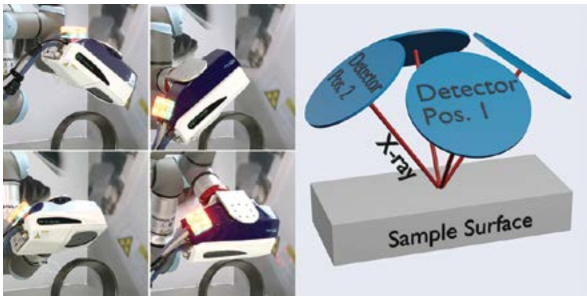

Figure 3: Stress matrix setup

Another option is the tilting of the sensor in four directions to collect the data needed for a stress matrix. Figure 3 shows the principal setup of the four measurements required. Both options can be easily automatized by the use of a six axis robot controlled by StressEasy.

Outlook

One of the future challenges in shot peening process development and control is not only the manufacturer's ability to evaluate his manufacturing processes, but also to understand the influence of different manufacturing parameters on the shot peening and result, resp. the residual stress achieved. Automated stress measurements are not only suitable to check parts in a production line, but also very useful if implemented in an internal research and development project to gain the best possible part performance and lifetime.

In order to achieve this goal in an efficient way it is helpful to move stress determination out of labs remote from production and to avoid major delays between production and quality control. The combination of a fast and easy-to-use X-ray stress analyzer with a flexible and user-friendly software solution like StressEasy is one major step on this way. In contrast to parts with demanding complex material conditions, properly shot-peened surfaces have the advantage to usually provide uniform and isotropic stress states which allow for simplified, accelerated and automatized measurements. Efficiency will further be increased when such standardized measurement tasks are performed under the supervision of material experts but carried out by well-trained operators.

For a StressEasy demo video, visit https://vimeo.com/559910333.