Chapter

Introductory Chapter: New Challenges in Residual Stress Measurements and Evaluation

Caterina Casavola, Claudia Barile, Vincenzo Moramarco and Giovanni Pappalettera

1. Definition of residual stresses and their relevance

Residual stresses (RS) are stresses present inside the materials and the structures even in absence of any applied external load. Residual stresses arise as a consequence of the complex sequence of steps starting from the material production, through machining, to final joining of subparts allowing manufacturing the final component [1]. Each production stage, in fact, such as casting, forming, joining, cutting, grinding, polishing, welding, heat treating, and so on, contributes to modify the pre-existing state of stress, and all of them add their specific contribution to determine the final residual stress field in the manufactured part [2].

Knowledge, control, and modification of the level of RS inside a given material or part become of capital importance by taking into consideration that residual stresses can impact greatly on the mechanical strength of the material, on its dimensional correspondence to design specifications, as well as on the corrosion resistance and on the fatigue life and durability of the part. It is well-known, for example, that tensile RS play a relevant role in reducing the fatigue life of the component so that several specific stress relaxation treatments have been developed in order to mitigate or eliminate their presence [3]. On the other side, the presence of a compressive stress field can have positive effects, and, due to this reason, some processes such as shot peening or laser shock peening have been developed to allow their introduction.

With respect to the recent past, it can be observed that mechanical designers have, nowadays, a greater awareness about the necessity to take into account also the presence of residual stress in their project. Relevance of RS, in fact, is now well assessed not only at academic level but also on the industrial side. At the same time, the multiplication and the evolution of the production techniques, the appearance of new disruptive manufacturing processes such as the additive manufacturing, the availability of more and more performing surface treatment techniques, the introduction of new coating technologies, and the request for increasingly better performing components result in a demand for more updated methods for residual stress evaluation.

The main aim of this book is to provide the reader with an overview of the principal challenges that research in terms of residual stress evaluation is currently facing including current limitations and potential future developments. At the same time, the reader will have an overview of the different materials, production technologies, and fields of applications where interest in RS evaluation is of capital importance but at the same time still not conveniently fulfilled by traditional and consolidated approaches.

2. Current trends in residual stress experimental analysis and numerical evaluation

The importance, and at the same time, the complexity, of obtaining an accurate experimental evaluation of the residual stress inside a material has led, along the years, to the development of many different approaches. Some of them such as the hole drilling method (HDM) and X-ray diffraction (XRD) are, nowadays, mature and widespread techniques ruled by specific standards [4, 5]. Even if they can be considered as benchmark techniques, it should be taken into account that, in many situations, they have some inherent limitations that cannot be discarded in some specific applications.

Hole drilling method, for example, cannot be conveniently used to determine the presence of residual stress too much far from the drilled surface. X-ray diffractometer is limited to the determination of superficial residual stress. Both the approaches cannot guarantee high surface resolution of the residual stress measurement.

More in general, it should be understood that each method developed for the residual stress evaluation has its specific advantages and drawbacks that make a specific approach appealing for a given application problem and inapplicable in some other situations. Having this in mind, however, it should be clear that current efforts are spent in the direction to increase the resolution of the measurement, both on the surface and in-depth, and to extend the capability to determine the residual stress present in the core of a given component. At the same time, also the development and improvement of nondestructive techniques for residual stress determination become of capital importance because this would expand the possibility to perform in situ evaluation.

Additionally, a further challenge is in the direction of adopting less expensive equipment and to reduce, at the same time, the cost and the time required for a single measurement [6]. A final direction of evolution of the research in the residual stress field is toward the RS characterization at the micro- and nanoscale. This is of interest by taking into account that, when dealing with high cycle fatigue and very high cycle fatigue conditions, the damage accumulation occurs at the grain level. Moreover, the introduction of micro- and nanomechanical systems requires an enhancement of the capabilities of characterization over this range scale. In the direction of improving the on-surface resolution, it worth mentioning the great effort that was done in the last years in the development of the contour method [7] that allows obtaining a complete map distribution of the residual stress along the cut plane, but it is limited to materials that can be cut by EDM machine, and it exhibits a higher level of uncertainty close to the edges of the measured surfaces. Magnetic methods such as magnetic Barkhausen noise [8] and acoustic Barkhausen noise [9] can be adopted as well to obtain residual stress map on a component, and current efforts are spent in the direction of accurate calibration procedures that take into account other factors such as the hardness, the crystallographic nature, or the complexity of the stress field that can impact on the measurement. Nevertheless, their adoption is limited to magnetic materials. The problem of increasing the depth of evaluation of residual stresses can be conveniently afforded, for example, by implementing synchrotron X-ray diffraction or neutron diffraction [10]; in both cases, however, very expensive equipment is required as well as long-term planning of the experimental campaign to access to the dedicated facilities. As an alternative some modifications of the hole drilling method such as the deep hole drilling method [11] and the slitting method [12] are studied and under development for in-depth measurements. In the direction of developing new nondestructive approaches, it appears now promising the possibility to combine optical and acoustic methods [13] to evaluate residual stress through the detection of the variation of the elasticity constant of the material. This is, incidentally, along another path of development followed by scholars in the last years aiming to combine multiple approaches in a single hybrid method (e.g., hole drilling/ring core). Capability to measure residual stress at the micro- and nanoscale is showing promising results, based, for example, on the adoption of the focused ion beam (FIB)-DIC micro-ring-core technique. This approach is very promising to be adopted for the evaluation of the type I, II, and III residual stresses. Raman spectroscopy, as well, is attracting a lot of interest in view of its capability to obtain microscale residual stress measurements [14]. It is worth mentioning, additionally, that efforts in improvement in experimental capability of residual stress evaluation impact also on the development and more accurate validation of modeling for numerical RS prediction. In this area the major challenges can be identified in the direction to extend the number of manufacturing processes and post-processes that can be modeled as well as to make the evaluation process faster and more accurate by introducing, for example, effects and features such as the kinematic hardening [15], phase transformation, and anisotropy.

Author details

Caterina Casavola*, Claudia Barile, Vincenzo Moramarco and Giovanni Pappalettera
Dipartimento di Meccanica, Matematica e Management, Politecnico di Bari, Bari, Italy

*Address all correspondence to: caterina.casavola@poliba.it

References

[1] Casavola C, Pappalettera G, Pappalettere C, Tursi F. Effects of strain's error on residual stresses calculated by HDM. Experimental and Applied Mechanics. 2013;**4**:395-402

[2] Totten G, Howes M, Inoue T. Handbook of Residual Stress and Deformation of Steel. Materials Park, Ohio (US): ASM International; 2002

[3] Withers PJ. Residual stress and its role in failure. Reports on Progress in Physics. 2007;**70**(12):2211-2264

[4] ASTM. E837-08 Standard Test Method for Determining Residual Stresses by the Hole-Drilling Strain Gage Methods. West Conshohocken (US): American Society for Testing and Materials; 2008

[5] EN15305:2008 Non-Destructive Test Method for Residual Stress Analysis by X Ray Diffraction. Bruxelles: CEN European Committee for Standardization; 2008

[6] Barile C, Casavola C, Pappalettera G, Pappalettere C. Analysis of the effects of process parameters in residual stress measurements on titanium plates by HDM/ESPI. Measurement. 2014;**48**:220-227

[7] Prime MB. Cross-sectional mapping of residual stresses by measuring the surface contour after a cut. Journal of Engineering Materials and Technology. 2001;**123**(2):162-168

[8] Casavola C, Pappalettere C, Tursi F. Calibration of Barkhausen noise for residual stress measurement. Experimental and Applied Mechanics. 2012;**4**:255-266

[9] Buttle DH, Dalzell W, Scruby CB, Langman RA. Comparison of three magnetic techniques for biaxial stress measurement. In: Proceedings of Review of Progress in Quantitative Nondestructive Evaluation. Brunswick (US): Plenum Publishing; 1989

[10] ISO/TS 21432. Non-destructive testing-standard Test Method for Determining Residual Stresses by Neutron Diffraction. ISO/TS Technical Specification; 2005

[11] DeWald AT, Hill MR. Improved data reduction for the deep-hole method of residual stress measurement. Journal of Strain Analysis. 2003;**38**(1):65-78

[12] Prime MB. Residual stress measurement by successive extension of a slot: The crack compliance method. Applied Mechanics Reviews. 1999;**52**(2):75

[13] Yoshida S, Sasaki T, Usui M, Sakamoto S. Residual stress analysis based on acoustic and optical methods. Materials. 2016;**9**(2):122

[14] Liu D, Flewitt PEJ. Raman measurement of stress in films and coatings. In: Yarwood J, Douthwaite R, editors. Spectroscopic Properties of Inorganic and Organometallic Compounds. 1st ed. Cambridge (UK): Royal Society of Chemistry; 2014. pp. 141-177

[15] Chakherlou TN, Yaghoobi A. Numerical simulation of residual stress relaxation around a cold-expanded fastener hole under longitudinal cyclic loading using different kinematic hardening models. Fatigue & Fracture of Engineering Materials & Structures. 2010;**33**(11):740-751