EASI-STRESS

EUROPEAN ACTIVITY FOR STANDARDIZATION OF INDUSTRIAL RESIDUAL STRESS CHARACTERIZATION

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D3.1 Towards technical specification requirements and user advisory protocols

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List of Abbreviations

LRI – Large-scale Research Infrastructure
RTO – Research and Technology Organisations
UAG – User advisory group
SGV – Sampled gauge volume

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Executive Summary

In order to develop and implement good practices for strain-scanning measurements, a set of specifications are described.

Starting first with a description of perceived barriers to industrial users which are common to both neutron and photon sources, baseline technical requirements are presented.

These technical requirements to be provided by both potential users, as well as for LRIs are described, alongside a route for improvement. The main vehicle for doing so is described, with the formation of a UAG.

Report on Implementation Process and Status of Deliverable

1. Introduction

For several decades, there have been multiple developments of specific instruments at Large-scale Research Infrastructures (LRIs), tailored to suit the needs of industry. Beyond the specific facilities that have been made available, global service and access frameworks have also been extended and uptake for some applications have greatly ameliorated the design and application of many unique material systems. This is true for both photon (x-ray), as well as neutron sources (Petry, Winfried, 2015; Suzuki, 2014).

Both an early and common use of these sources has been to examine the state of internal strain of metallic components. Measurement of this strain imparted by a myriad of materials processing techniques has been important from a product validation perspective, to interrogate remediation processes and fitness for service in the high-value manufacturing sector, to further validate computational processing models for the same, and for high-volume manufacturers.

However, there still remains a barrier to entry for a number of industries in both the high-value and high-volume manufacturing sectors, even though there are long-standing, recognised benefits to employing these facilities by industry (Felcher, 1989). As part of the remit of EASI-STRESS, this report serves to introduce a framework and specifications to address these perceived barriers. This report will first describe these perceived barriers which are common to both neutron and photon sources, but unique for the end result: a resolved residual stress field in a given component, with a given material system. Then, the most immediate route for remediation will be presented, the formation of a User advisory group (UAG).

2. Background

Currently, there are multiple routes to access LRIs for the purposes of assessing residual stresses, and indeed, many specific instruments housed at LRIs which are either purpose-built for this purpose, or can be employed with some restrictions. Currently, there is no broad overview of all potential instruments that could be used, nor the limitations for their use. In order for a potential user to employ these instruments, either there is an existing relationship with the LRI and therefore a local contact which can be contacted to work through initial scoping, and finally down to a specific instrument and instrument scientist who can further guide the potential user into achieving a final measurement. The regularity and frequency that this service is accessed can be complicated by knowledge management aspects attributed to institutional and/or corporate memory.

Therefore, there is an opportunity to address these issues at a high level, specifically for the measurement of residual strain in polycrystalline engineering components, agnostic to LRI and nature of the underlying instrument. It is therefore necessary to:

I. Generate a series of technical protocols that describe a component to be assessed in a standardized way.

II. Access current instrument specifications and develop a harmonised technique such that they can be paired more effectively with application.

III. Advise on a harmonised data format which communicates both the underlying component and results from a variety of instruments.

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Overview of overall programme structure

Figure 1 shows the overall arrangement of the work package structure within EASI-STRESS. The activity described in this report is contained within WP3, running in parallel with WP4.

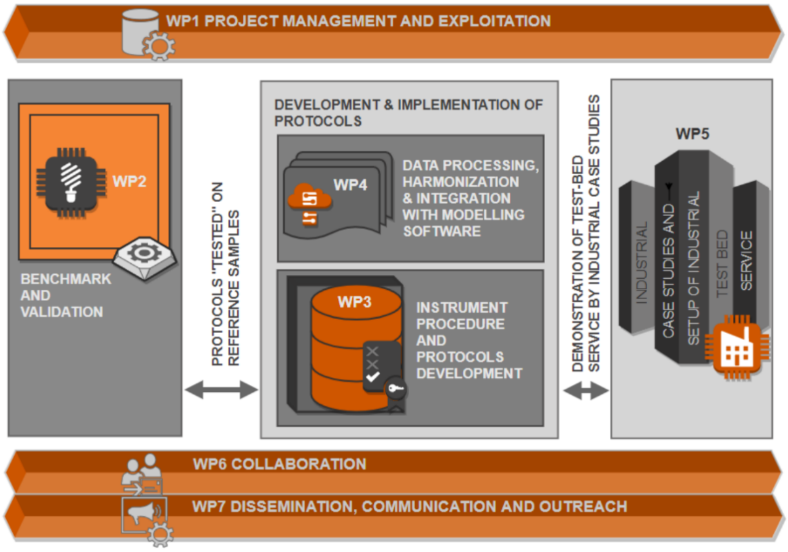

Figure 1: EASI-STRESS WP structure

The activity described in the above section, items I & II are to be carried out in WP3, and primed by components and instruments to be considered in WP2. The activity described by item III will be the main connection with WP4 and WP5.

Technical requirements

In order to provide enough information to prospective LRIs and those most closely involved with making measurements at these facilities, there can be an escalating degree of information that is required, depending on the component in question. The underlying premise, regardless of instrument, is that *strain* is measured at specific positions within a given component, by examining how either neutrons or x-rays are diffracted. Elastic strain is a measure of deformation due to the imposition of stress, and therefore a starting dimension is required to tabulate a difference. These elastic strains are sampled and averaged at gauge volumes (SGVs) centred at specific intervals within the component. *Stress* is then calculated from these strains, and in order to acquire stresses, multiple strain orientations are often required. Ultimately, what is desired by the end user of these measurements are these resolved stresses at given locations within the component, typically balancing over a length scale greater than a millimetre.

There are sources of uncertainty when proposing and specifying these measurements. The first is an estimate of the instrument time required to achieve a specific measurement campaign. This can be an estimate of time required for both actively employing the instrument, and that for off-instrument preparation of the component and/or changing the instrument configuration and calibration. For example, the time to achieve enough discrete interactions between beam and SGV (*i.e.* count times) is complicated by:

i) the distance through which the beam has to travel through the component;

ii) the nature of the underlying microstructure that can attenuate or otherwise affect elastic diffraction; and

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iii) the number of reorientations of the component required, either for the multiple principal strains required, or to alleviate aspects presented by the two preceding complications.

Furthermore, there are issues associated with interrogating strains close to the surface of components, or those that vary on length scales which are less than a millimetre internally. These length scales are sometimes addressable with some materials through the deconvolution of intersecting/overlapping SGVs, or with smaller SGVs attainable with x-ray techniques. However, achieving sub-millimetre resolution presents greater difficulty, and is only possible on very small samples with specialised instruments at select LRIs (Kutsal et al., 2019; Simons et al., 2015; Staron et al., 2014).

Based on the above description of the requirements, a standardised methodology for describing the component or system of interest such that they can be best paired to a strain-scanning instrument are as follows:

- *Scope*: Declaring the underlying intention of the strain measurement, e.g. to complement existing computational modelling, and the parameters by which stress is to be calculated from strain.
- *Geometry:* Size, weight, measurement region and directions, including datum location(s) *i.e.* reference or fiducial points to locate measurements within the component.
- *Material condition:* Alloy type, microstructural scale, notional crystallographic parameters and potential textural effects
- *Measurement conditions:* Specifications for departure from ambient, static conditions. For example, externally applied loads to the component, temperature or other environmental aspects.
- *Resulting measurement criteria:* Measurement resolution, and the minimum number of points required. Aspects of this include definition of an SGV, as well as necessary strain resolution.
- *Reference samples:* A description of what shall be used for a stress-relieved sample which reciprocates the material condition with the absence of stress.

The provision for a strain-scanning *experiment* is one that captures the above details and applies underlying diffraction principles, balancing the geometry of both the SGV and component with count time. The exercise is and will remain best described as an experiment. While there have been numerous measurements of similar polycrystalline and other polycrystalline systems, the crossroads between identical component configuration, instrument and data analysis are rarely met more than once. This is because problems deemed necessary to employ LRIs are rarely addressed more than once.

To reduce some of the planning overhead associated with planning these experiments, there has been development of open-source virtual laboratories for “planning, visualising and setting-up strain scanning experiments” (James et al., 2004; Stephen, 2021). The utility of these is still hampered by unknown specifics of beam interactions with specific material systems, and therefore count time estimates are often established based on historical or instrument scientist experience. Further hampering this approach is the additional overhead associated with maintaining both a physical and faithful virtual version of the same instrument such that both retain relevance with the overall user community. However, it remains that there is a unified specification and taxonomy which can be employed by both neutron and x-ray strain scanning instruments. This common set of specifications which are germane to strain-scanning, and serve as a launching point to a sustainable *in silico* premise.

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- *Scope*: Reporting standards that are paired with the underlying rationale for measurement; for example, the data reporting requirements can differ with respect to supporting a computational model, versus a purely non-destructive measurement.
- *Geometry:* SGVs which can be achieved or are typically used, including near-surface techniques, capacity of positioning system. This includes the envelope and maximum distance from beam and overall weight of the component. Where instrument configuration changes are necessary during the campaign, an estimate of the time required to effect these.
- *Material condition:* Estimated count times at minimum and maximum penetration for a range of polycrystalline systems with a quality metric tied to diffraction peak statistics.
- *Measurement conditions:* Details of ability to apply external loads and environments during measurement conditions.
- *Resulting measurement criteria:* Spatial resolution, accuracy, and precision/bias which can be attained with the combination of positioning, alignment procedure and beam optics and detector combinations; these in turn will dictate the final strain resolution that can be achieved on the subject instrument.
- *Reference samples:* Sample datasets from previous campaigns for the specific instrument, which place less focus on specific outcome, but rather time or resource allocated for a given outcome.

Many of the above details are made available or are easily accessible in varying formats. The current status of the delivery of these technical specifications will draw closer to term as WP2 and WP5 and activities continue. The specific model and format for describing these technical requirements for performing LRI experiments become clearer as proposals are submitted to different LRI members. The results of which, alongside historical data, will provide the basis for developing a harmonised data format which both records results obtained and subsequently employed by industry on a parallel basis. Pivotal in ensuring that this process is a success will be the establishment of a User Advisory Group, described subsequently.

3. EASI-STRESS User Advisory Group scope

A set of specifications for various LRI instruments will be identified after interaction with the partners of the consortium. The scientific staff of the facilities will advise on the possibilities offered both currently and upcoming innovations with instruments at LRIs. The representatives from the industrial community will advise on their needs and constraints. A crucial bridging role will be played by the partners acting at the interface between industry and LRIs. The UAG will provide regular feedback on the activities completed in other work packages in the EASI-STRESS programme. This section serves as an introductory proposed scoping of the UAG. This includes remit, group membership, working methods and protocols, and other aspects.

Remit

- To provide recommendations to industrial users of European LRIs for engineering purposes, specifically to obtain residual stress measurements, balancing timeliness and technical feasibility;
- To inform access routes and application procedures for European-wide characterization facilities specifically addressing industry requirements; and
- On a continual basis, improve access, tools and protocols through recommendations within the EASI-STRESS framework environment.

Composition and membership

- A representative from each LRI which represents engineering instruments historically for residual stress measurements

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- One or more industrial representatives which have employed these services previously
- One or more RTO

Membership numbers and requirements are defined on the basis of stakeholders of EASI-STRESS. If additional members are required, the group should balance the expertise required and potential candidates. Advertising of vacancies will be carried out according to the equality and diversity mandates set forth by the European Commission.

Working methods and protocols

Initial protocols Within the current EASI-STRESS consortium and the referenced work packages, the initial protocols will be developed employing benchmark components, and initially tested with the same. The routes for accessing each of LRIs currently involved will be mapped and routes for harmonisation will be developed. The goal is to provide a simplified application procedure which is harmonized with each LRI's facility access procedure as a minimum, informed by the technical expertise of the UAG. It is important to highlight that the developed protocols are to complement, rather than replace the current routes and procedures for gaining access to LRIs, and therefore it is outside the remit of this group to decide scientific merit or whether access time should be allocated.

Developed protocols Comments and feedback from the UAG to users is the primary output in a timely manner. Feedback may include the recommendation of a different route (photon versus neutron), that preliminary trials be conducted to expedite or define suitability of samples prior to access being granted amongst other aspects. Where conflicts are identified, either LRI availability or that a better suited complimentary technique is available, then the recommendation of other ancillary characterization resources will be made.

Continuous improvement The form of feedback and assessment practice from the UAG will be revised as LRI access routes change, but also as there are developments in improving practices in residual stress characterisation techniques.

Code of practice The UAG's members should at all times pursue selflessness, integrity, objectivity, accountability, openness, honesty and leadership. This extends to declaring any and all conflicts of interest. All applications from developed protocols are considered to be strictly confidential on a commercial basis, and coincide with all data protection protocols held by the respective stakeholders.

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