ADVISE project
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WP3 Dynamic Calibration

Deliverable D3.4

Specification of 'cyclic' reference material

Partners involved: EMPA, AUK, DD, JRC, UNIL, LTSM-UP, HPS, MSU

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Reference Material

A Reference Material is defined as material, sufficiently homogeneous and stable with reference to specified properties, which has been established to be fit for its intended use in measurement [1]. Reference materials provide a simple definition of the measured quantity that can be traced to an international standard and can be used to assess the uncertainty associated with a measurement system. In the ADVISE project[2], efforts have been oriented to provide reference materials for calibration of systems capable of measuring three-dimensional deformation fields induced by dynamic loading. The purpose of this document is to describe a Reference Material that will allow the calibration of full-field optical systems that are used to capture dynamic deformation fields associated with cyclic loading. In a second and related document, a reference material for transient and non-linear loading cases is specified.

Calibration of full-field optical deformation measurement systems is an essential step in providing traceability and promoting confidence in relation to displacement and strain distributions obtained from experiment. Calibration is also highly desirable when the full-field experimental data is used to validate computational models employed in engineering design. Formally, calibration is defined as an *'operation that, under specified conditions, in a first step establish a relation between the quantity value with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step uses this information to establish a relation for obtaining a measurement result from an indication'* [1].

Design concept

The aim was to design, manufacture, and demonstrate a physical Reference Material that generates a known and reproducible displacement/strain field in a defined gauge-zone, as a function of an applied dynamic load. An iterative design process has been followed involving analytical, computational, and experimental mechanics techniques in order to reduce possible sources of experimental uncertainty and to simplify the manufacturing process. The rational decision making model[3] was employed to guide the definition and development of the Reference Material, as already performed in the design of SPOTS reference material[4]. In this process, essential and desirable attributes of a Reference Material that would facilitate an effective calibration procedure were identified. Then, a set of designs were created. The extent to which each design possessed the attributes was assessed in order to highlight the designs which best fitted the requirements. This approach allowed a large search space so that many widely differing solutions could be considered and the inappropriate dominance of previously utilised solutions could be avoided. As a first step, a comprehensive set of possible attributes were proposed and used as a basis of an ADVISE questionnaire to engage the engineering community in the weighing of these attributes. The surveyed communities included ADVISE partners and participants of the Society for Experimental Mechanics 2009 Spring Conference (Albuquerque, NM). Contributors were asked to weigh the attributes provided and to propose any extra

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[1] ISO/IEC guide 99:2007, International vocabulary of metrology — Basic and general concepts and associated terms

[2] ADVISE, Advanced Dynamic Validation through Integrated Simulations and Experimentation, www.dynamicvalidation.org

[3] Cross N., *Engineering Design Methods* (John Wiley & Sons, London, 1989)

[4] *Guidelines for the Calibration and Evaluation of Optical Systems for Strain Measurement, SPOTS,* www.opticalstrain.org

attributes that they felt should be included. Attributes were divided into those associated with the displacement field the Reference Material should generate, and those associated with the general embodiment of the Reference Material. Four essential attributes for the displacement field were identified: range of displacement inside FOV; presence of out-of-plane & in-plane displacements; in situ verifying the performance; in case of cyclic loading: data extracted through a cycle. Three essential attributes for the physical embodiment were identified: boundary conditions are reproducible; portable; and robust. Sixteen desirable attributes were also defined and used to guide the choice of preliminary design. The next step in the rational decision making model was to put these constraints aside, and to brainstorm the widest set of possible candidate designs conceivable to the ADVISE partners. Subsequently these design concepts were tested against the essential attributes and those designs that did not possess all of these were rejected. As a result of this filtering process, nine quite different candidate designs were left. The designs selected were then evaluated once more, this time against the desirable attributes, which led to the identification of two favoured candidate design, one based on a plate held in a monolithic rectangular frame, the other based on a cantilever. An FEA study (COMSOL Multiphysics) was then undertaken to model the behaviour of the complete RM structure to understand and optimise its dynamic behaviour, and to finalise design detail and dimensions before prototype manufacture. A first prototype of Reference Material was manufactured. After an experimental measurement campaign was conducted on the first prototype, design refinements were made, and a second prototype was manufactured.

When excited, the Reference Material has a pre-dominant out-of-plane displacement. In-plane (strain) and out-of-plane deformation are available for the calibration process. By tilting the Reference Material, a displacement in any direction can be generated, and x, y and z displacement components can be considered for calibration.

Design specifications

The design of the Reference Material consists of a plate held in a monolithic rectangular frame (Fig. 1). The monolithic design ensures a high degree of repeatability and eliminates any slip phenomena due to clamping at boundaries and fixation points. The design is fully parametric, with normalised dimensions based on the width and height of the plate, *a* and *b* (Fig. 2). This allows the Reference Material to be manufactured from a range of materials and scales from micro to macro.

There should be no residual stress in the base material for manufacturing, since that is the primary source of possible discrepancy between measured and predicted behaviour. The use of cast aluminium alloy 5083 (Peraluman, AlMg4.5Mn0.7) demonstrated very good results.

Ligaments were designed to hold the plate inside the frame with an orientation of 45 deg to balance in plane displacement/strain along x and y direction (Fig. 3). Waffle-like slots with dimensions normalized on *a* and *b*, are provided on each ligament to decrease the constraint of the plate, to increase the magnitude of out-of-plane displacement and, as ultimate aim, to reduce the difference between the predicted and measured value of displacement/strain field in the Reference Material. The ligament thickness is the same as that of the plate.

The dimensions of the plate were defined with an aspect ratio of a:b = 1.5 to allow comparison with an analytical model, for which there is a mode shape description for a plate with pinned corners, involving a series of some 10 sine terms.

Some of the design details are discussed below in which the roman numerals refer to those marked in Fig. 2 and Fig. 3.

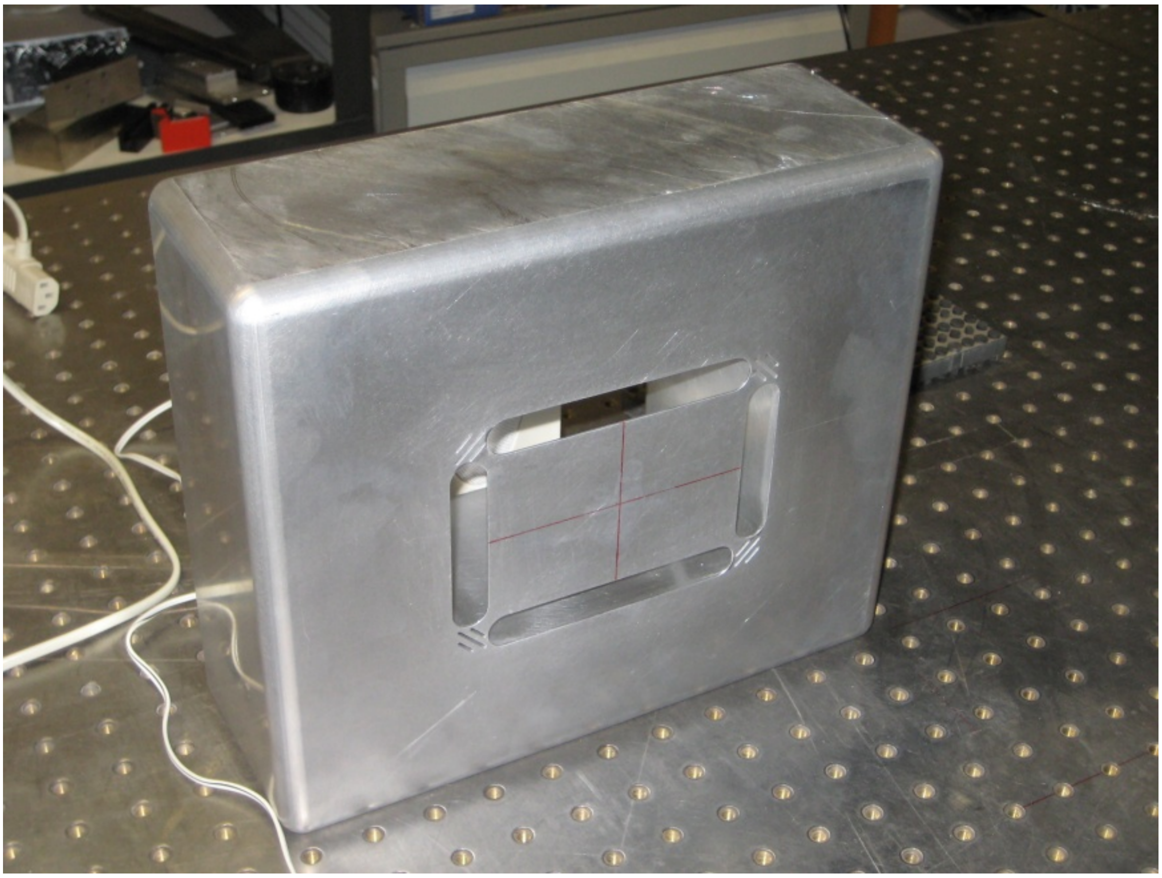

Fig. 1 Prototype of ’cyclic’ Reference Material manufactured from cast aluminium alloy 5083 (Peraluman, AlMg4.5Mn0.7)

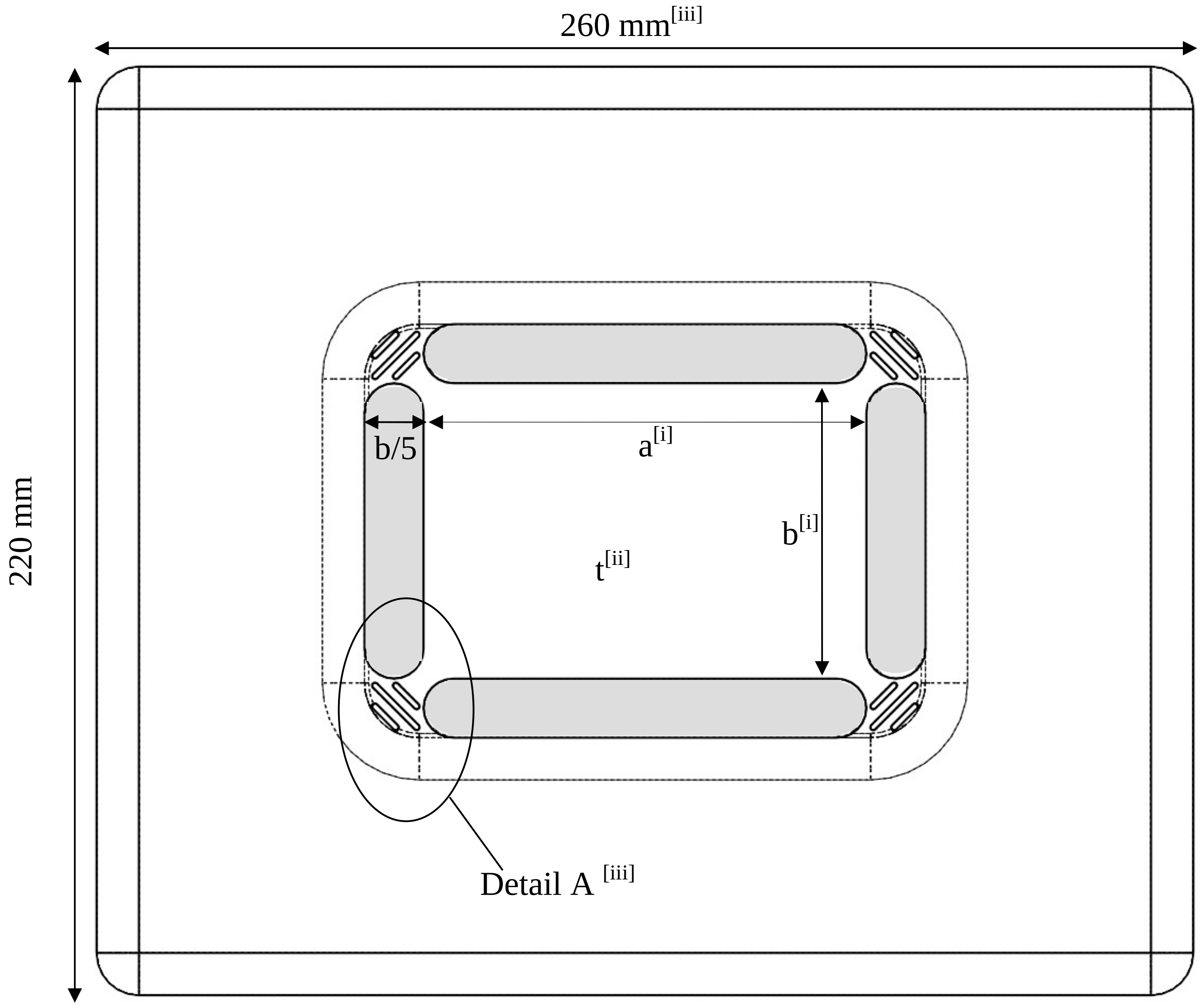

Fig. 2 Schematic of the Reference Material with normalised dimensions based on the dimensions of the plate a and b. Detail A of the ligament is shown in Fig. 3

i. Dimensions of the plate *a* and *b* are parametric and defined by aspect ratio value (a=1.5b). The Reference Material prototype has a plate of 105x70x1 mm.
ii. In the prototype, the thickness *t* of the plate is 1 mm (0.014b < t < 0.015b), based on a preliminary FEA study, in order to provide a good amplitude of out-of-plane displacements for calibration process.
iii. All dimensions of the ligament design, Detail A, are normalised on the dimension, *b*, see Fig. 3.
iv. On the inside side of the plate, a fillet between ligament and frame is provided (Fig. 4) in order to reduce the risk of fatigue failure during dynamic loading. The size of the fillet is the same of the plate thickness, i.e. *t*.

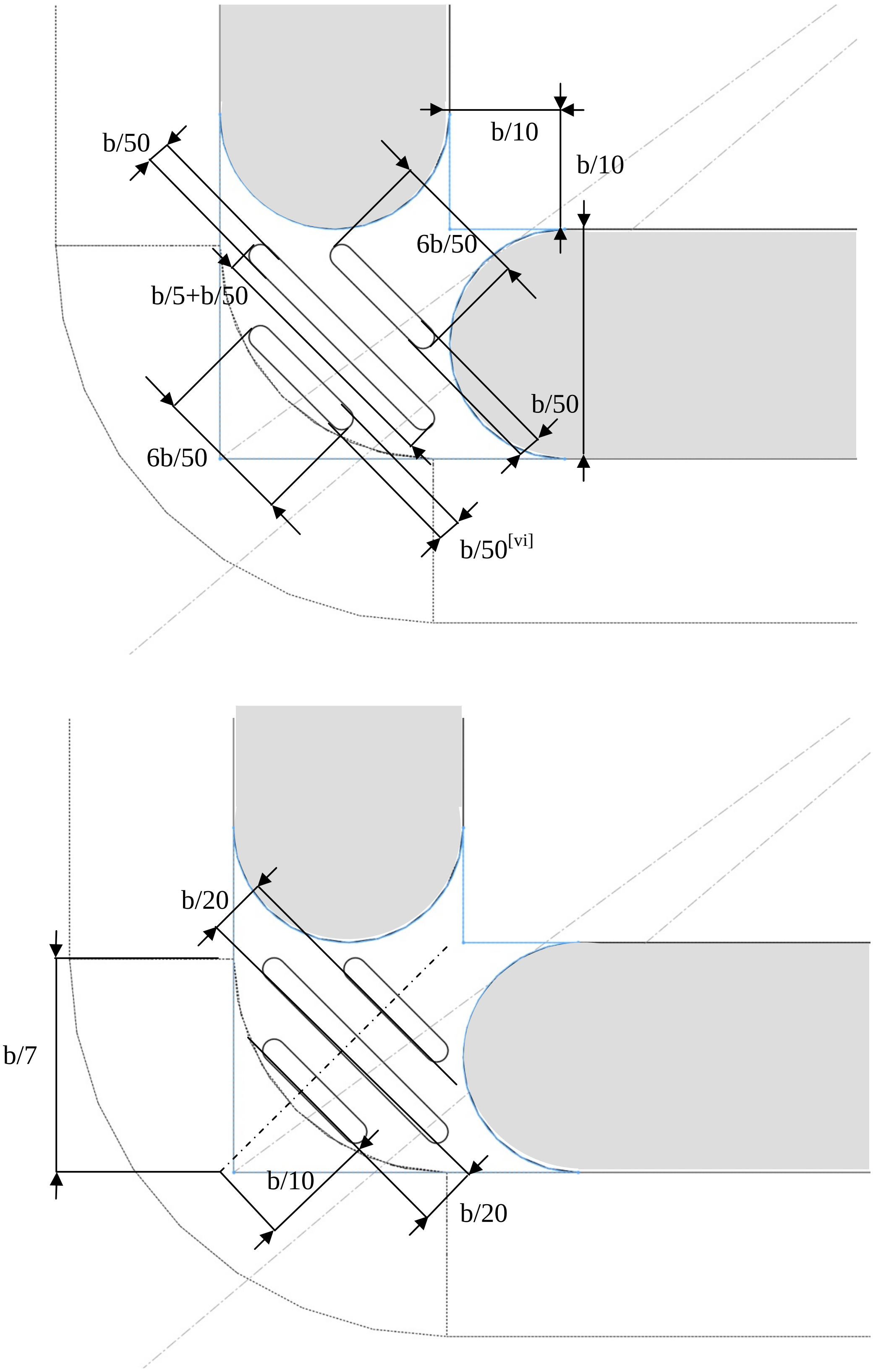

Fig. 3. Detail A in Fig. 2 showing the ligament design.

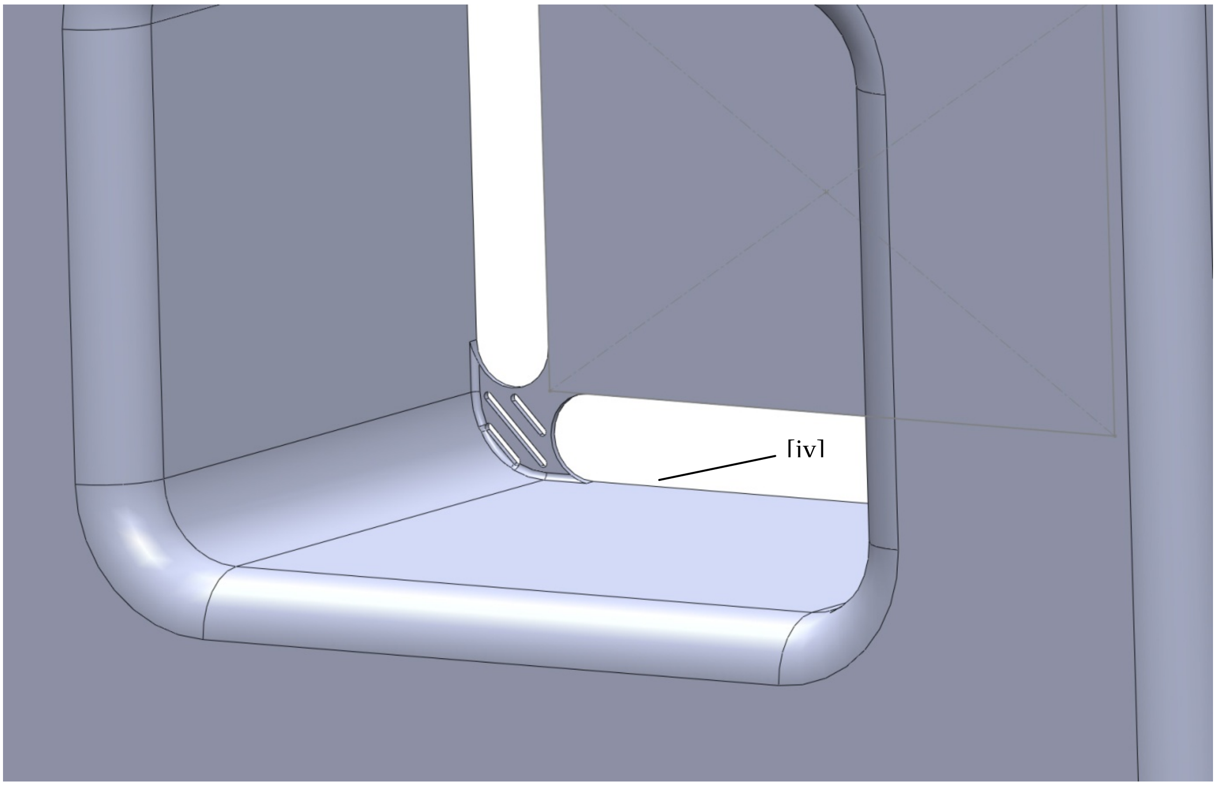

Fig. 4. Schematic showing the fillet beneath the ligament.