A NEED FOR NEW STANDARDS: COMMUNICATING SHAPE TRANSFORMATIONS IN THE TECHNICAL DOCUMENTATION OF PRODUCTS

The use case of a generic mini-gripper sheds light on the benefits that a new standard could bring to the engineering and design of shape memory materials.

Eujin Pei, Brunel University London

Christopher Leung, University College London

Shape memory materials have been used in a growing number of commercial applications, including stents, heart valves, and guidewires in medical applications; anchors, sleeves, and screw devices in mechanical applications; vortex generators, torque tubes, and flaps in aerospace applications; industrial bearings, gears, and ventilators in automotive applications; as well as blinds and shades in architectural applications. Taking a step further, research over the past decade has shown that shape memory materials can be effectively utilized with additive manufacturing processes to produce high-value products.

4D PRINTING

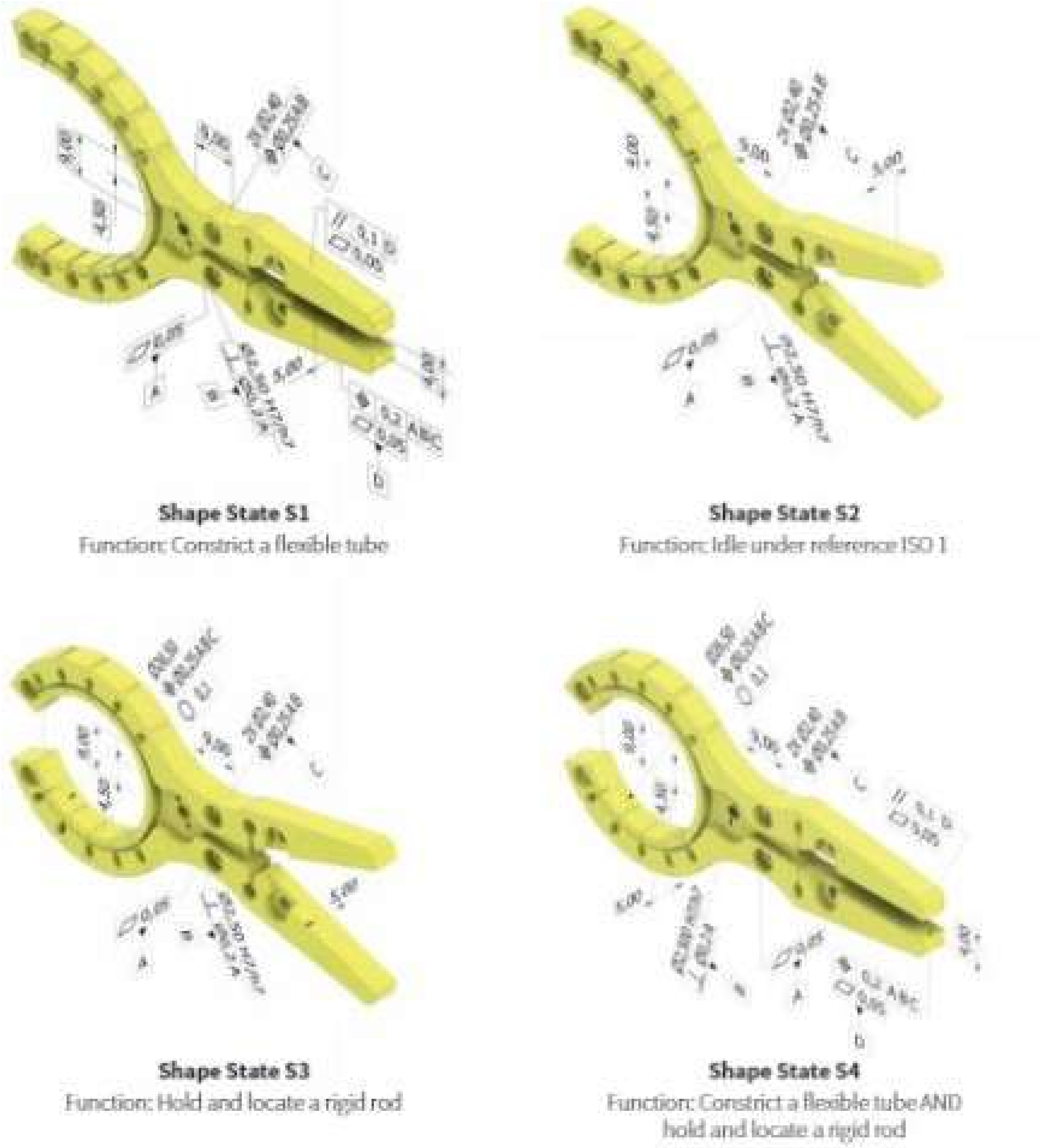
Advances in additive manufacturing have enabled functional grading and multi-material deposition to produce what are termed "4D printed" parts that are net or near net shape; creating highly complex features that are difficult to produce with conventional manufacturing processes. In this context, 4D printing affords the design engineer with the possibility to program shape transformations that are required to meet different functions by selectively distributing the stimuli-responsive properties of shape memory materials into a part's geometry. An operational implication of 4D printing is a shape transformation or variable properties in response to the passive exposure to an environmental stimulus by the free exchange of energy or matter. With greater awareness of the environmental impact of industrial activity and emphasis on low-impact sustainable development, circular economy, and net zero targets, 4D printed parts have the potential to foster the creation and development of specialized high-value products. Examples may include parts that operate passively without the need for an external power source or with fewer electromechanical components through part consolidation, greater material efficiency, and the potential for material recoverability at end-of-service.

A fundamental challenge exists: How to ensure that the design, manufacturing, and functional intent for 4D printed parts can be accurately and unambiguously communicated between stakeholders across the design, manufacturing, inspection, and supply value chain? One argument states this requirement is not exclusive to shape memory materials used with additive manufacturing processes, but can also be applied to shape memory material properties used in conventional manufacturing processes. Until now, the main emphasis has been on the need to develop standards that can be used by engineering and design teams to accurately represent the shape transformation of non-rigid bodies so that shape memory products can be more widely adopted, more comprehensively tested, and reach a high level of industrial maturity and acceptance. With such a standard being made available at the engineering and design stage, it is expected that the end product would be able to conform to stringent industrial testing, metrology, and quality control requirements.

BRITISH STANDARDS

In the context of national standards for technical product realization (TPR), the British Standards Institution committee TPR/1 is responsible for the U.K.'s input to the international ISO/TC 10 Technical Product Documentation and ISO/TC 213 Dimensional and Geometrical

Fig. 1 — Use-case generic mini-gripper.



Shape State S1
Function: Constrict a flexible tube

Shape State S2
Function: Idle under reference ISO 1

Shape State S3
Function: Hold and locate a rigid rod

Shape State S4
Function: Constrict a flexible tube AND hold and locate a rigid rod

Fig. 2 — Shape states S1, S3, and S4 share a common datum reference frame (DRF) as defined in S2 under reference conditions to ISO 1.

Product Specifications and Verification, dealing with the process for design implementation, geometrical product specification, graphical representation of engineering drawings and 3D modeling, and technical documentation. In September 2022, TPR/1/8 Technical Product Realization—BS 8888 Technical Product Specification committee established a technical sub-committee TPR/1/8/1 for the "design of graphical symbols for use in the technical documentation of products—4D printed parts—shape transformations" to undertake this work.

USE CASE

The framework for this technical product documentation is based on three concepts. These are illustrated in the use case of a generic mini-gripper shown in Fig. 1. First, the shape state (S<num>) expresses the functionally critical features of the part in each of its shape transformations using the geometrical product specification (GPS) language (Fig. 2). The mini gripper's four functions are: to constrict a flexible tube, remain idle in a NO (normally open) position, hold and position a rigid rod, and to constrict and hold at the same time, giving four shape states. The allowable deviation in dimensional size and tolerance in geometric form of the functionally critical features on the part for each shape state may be expressed by directly annotating the features on the

Shape Transform	Stimuli	Magnitude and Intensity	Threshold	Latency
From→To	Mode	Spec./Tol.	Spec./Tol.	Spec./Tol.

Fig. 3 — Transformation control frame.

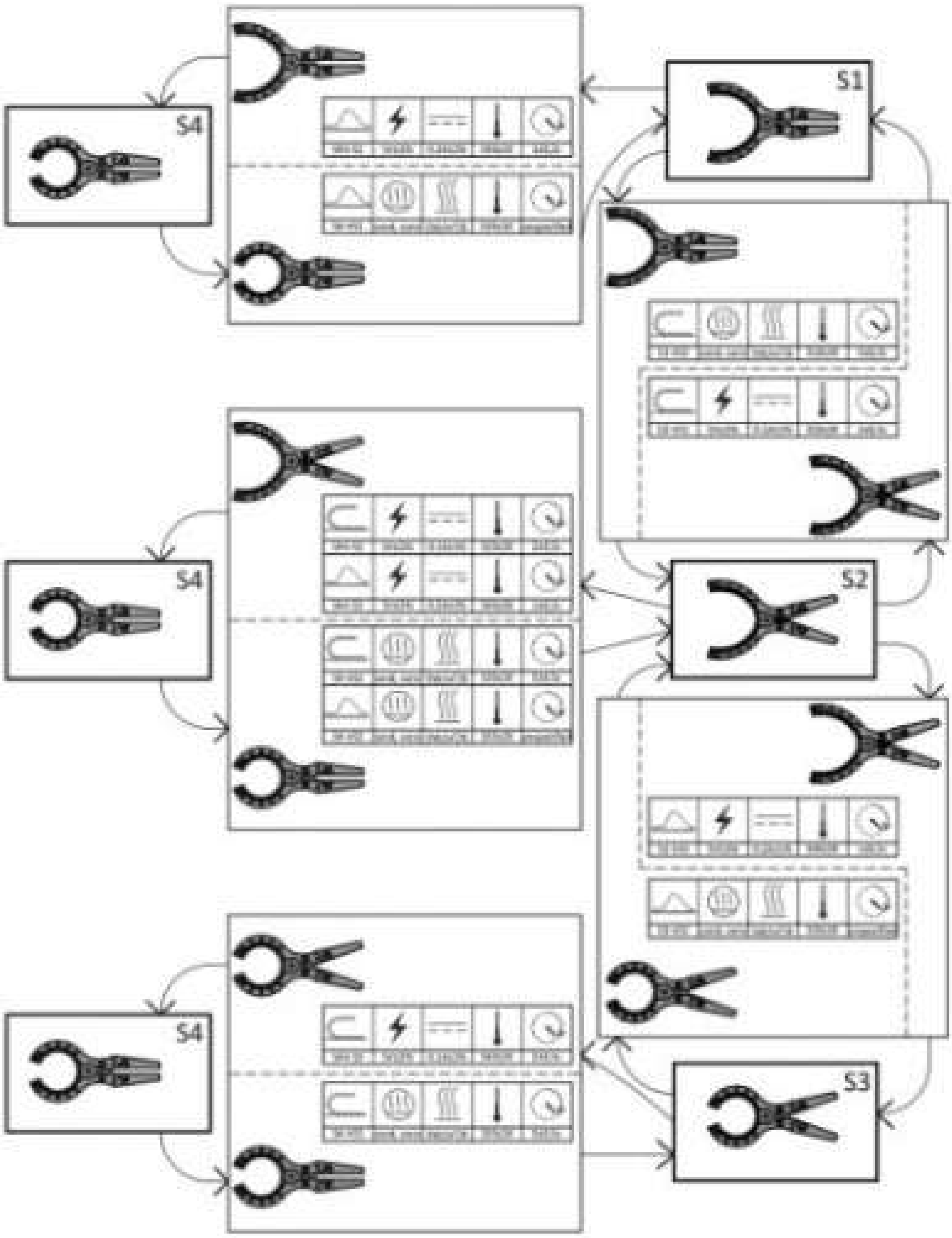


Fig. 4 — Bill of transformations.

solid geometry of the part in the STEP file format to ISO 10303 with model-based definitions (MBDs) as shown in Fig. 2.

Second, the transformation control frame (TCF) defines the rules of transformation between shape states (Fig. 3). Third, the bill of transformations (BoT) schedules the intended sequence of all TCFs to fully describe the part's shape transformation between all four shape states S1 through S4 as shown in (Fig. 4).

CALL FOR CONTRIBUTIONS

This proposed new standard will be used within technical product documentation (TPD), geometric product specification (GPS) and engineering drawings within British standard BS 8888 that defines the requirements for technical specification of products. The authors are seeking to receive industrial input, expert feedback, as well as use cases that could be used in the standards document. Contributions to these use cases would aid illustrating how the proposed standard can be used and to study its relation to existing well-established workflows. Interested parties, including designers, test engineers, and metrologists working with parts involving shape transformations where the proposed standard could be applied may contact the authors for further information. ~SMST

For more information: Eujin Pei, Brunel University London, eujin.pei@brunel.ac.uk; Christopher Leung, University College London, christopher.leung@ucl.ac.uk.