Thermal Stress & Distortion during Additive Layer Manufacturing

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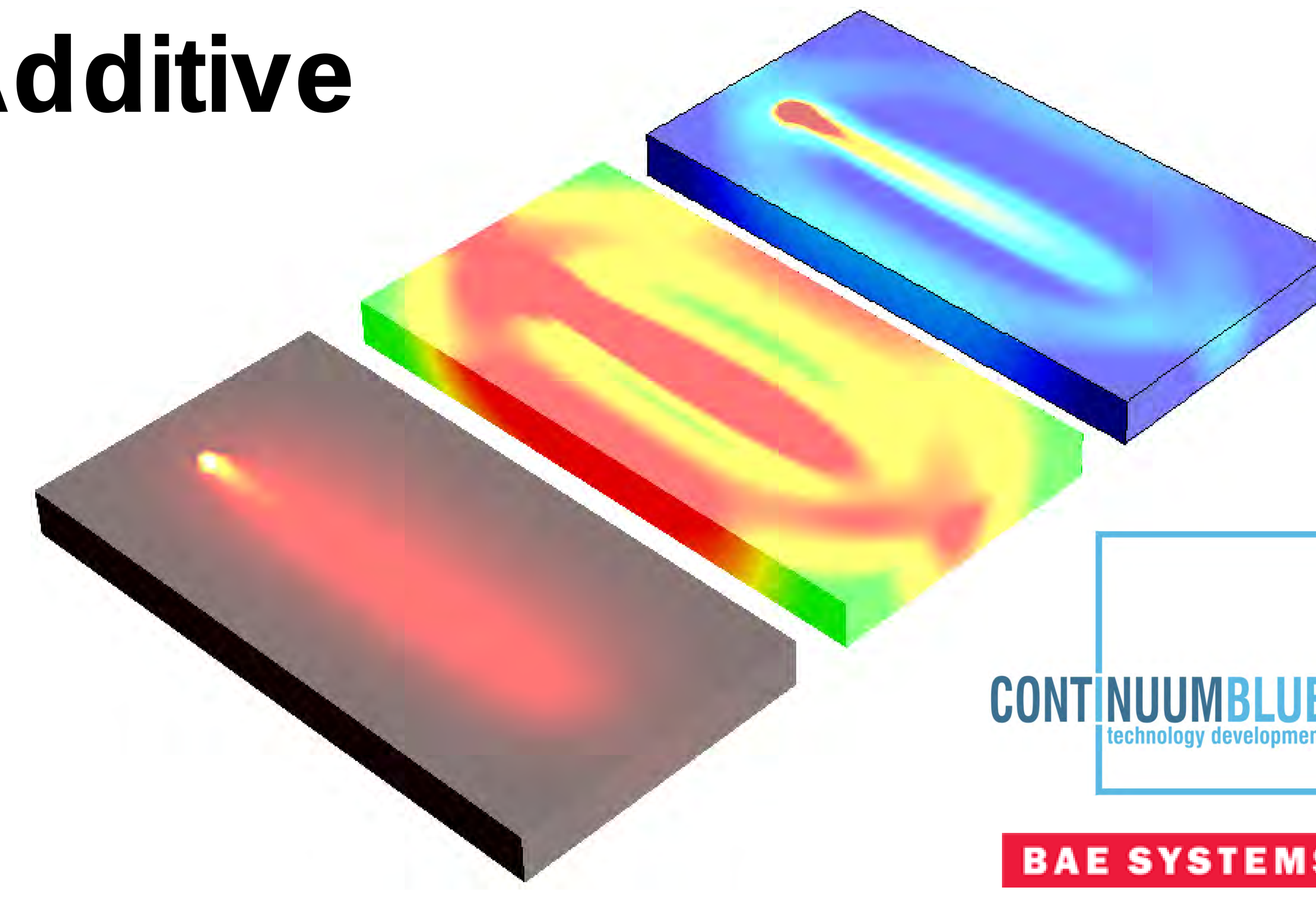

INTRODUCTION

Product manufacture at the turn of the last century dramatically changed with the introduction of mass production. Yet again, this sector is about to change, with the advent of new additive layer manufacture (ALM) technologies making it cost effective, easily available & readably accessible. ALM machines now have the ability to produce products in a range of materials & colours in a single process, allowing product designers to produce intricate pre-assembled items, which would be unconceivable & prohibitively expensive with traditional methods. One such sector which is trying to make full use this technology is aerospace, where reducing the cost of large components such as fuselage frames, would help reduce cost & production times, dramatically decreasing material waste & the carbon footprint. Although ideal, ALM has draw backs when producing large components economically out of metal alloys, these include distortion & residual stresses. Distortion results in low production yields, while the ingress of residual stresses, not readably detectable, could result in premature fatigue failure of the component during service.

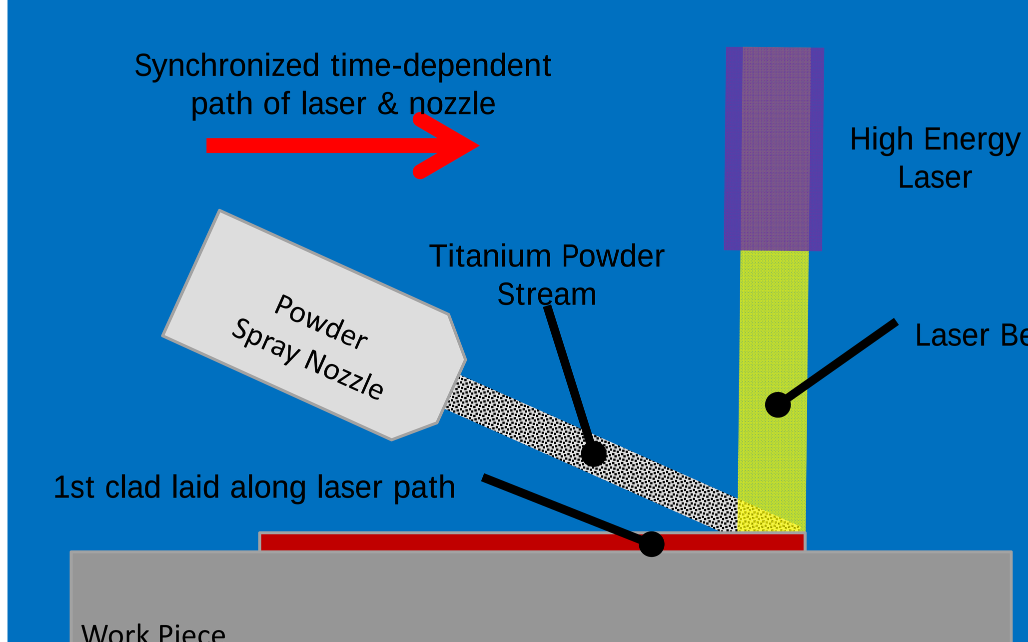

Figure 1. Schematic of powder consolidation with laser heating

AIM

To develop a 3D transient thermal-stress model to predict & understand distortion and the development of residual stresses & strains which remain following manufacture, using multilayer laser solid freeform fabrication (LSFF), and to use this model to find the optimal path, speed & power of the laser head in order to minimise or eliminate distortion & residual stresses & strains.

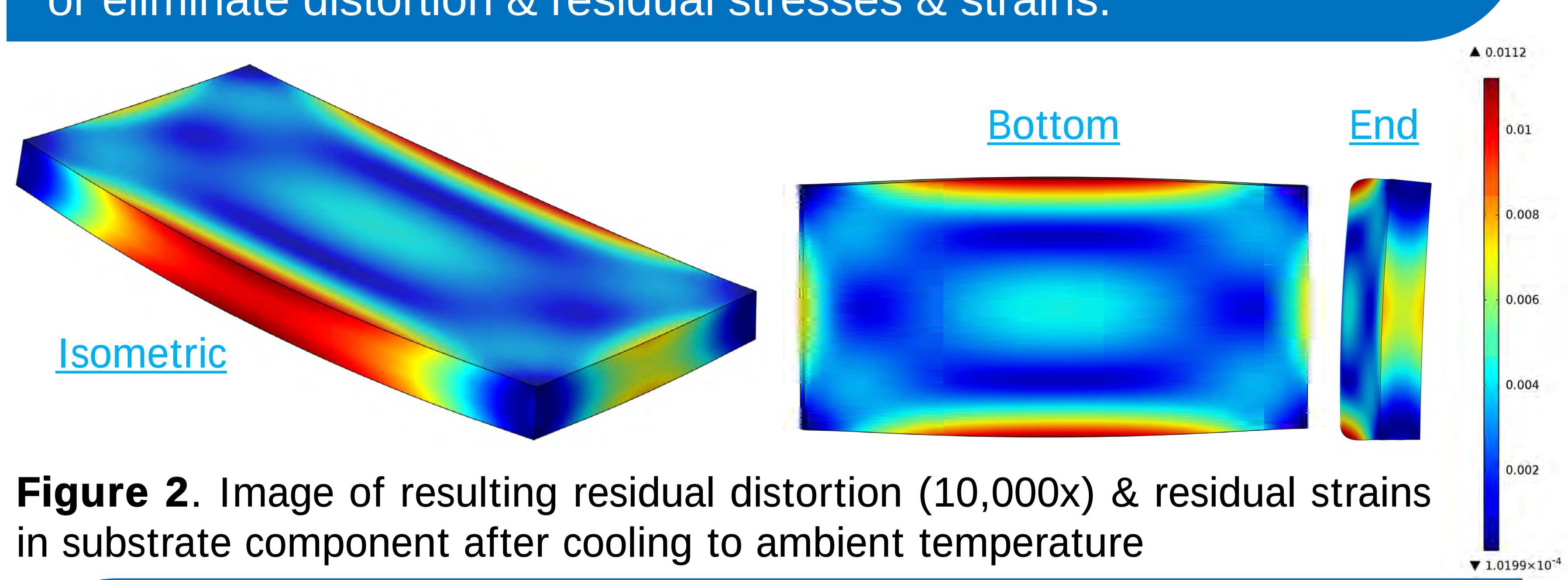

Figure 2. Image of resulting residual distortion (10,000x) & residual strains in substrate component after cooling to ambient temperature

METHOD

A transient thermal-stress model coupled with a PDE, was used to describe the powder consolidation of titanium beads using a high powered laser on to a work piece (substrate). Two 3D geometries were used to describe the coupled physics. A simple rectangular block to describe the substrate & the fusing of the titanium powder, and a circular disc to describe the path dependent focal region & penetrative depth of the lasers electromagnetic radiation. An interpolation function was used to describe the transient path of the laser. Temperature dependent material properties & flow characteristics were implemented in the model to describe the metal alloys response.

RESULTS

The resulting distortion from a single sweep of the laser, in a regular rectangular pattern resulted in a relatively low degree of distortion, & localized residual stresses. In this instance the work pieces' upper surface is rapidly heated & allowed to cool following the path of the laser. This results in extremely high localized thermal loading & melt flow, in the mid region of the plate, combined with a delay in heat dissipation via conduction to the surrounding material. However, this localized thermal load in the central region of the plate leads to high residual stresses & strains along the mid-sections of the side walls on the periphery of the plate following cooling (Figure 3). This is due to the mid region of the plates expansion, resulting in the sides of the plate yielding & work hardening over successive sweeps from the laser path & its compounding effects. The resulting distortion due to these residual stresses (Figure 2), causes the plate to dome in a concave-convex manner, where a concave profile is observed on the upper surface & convex on the lower surface after cooling. However, during additive layering the opposite was observed, where the convex profile is observed on the upper surface & concave on the lower surface.

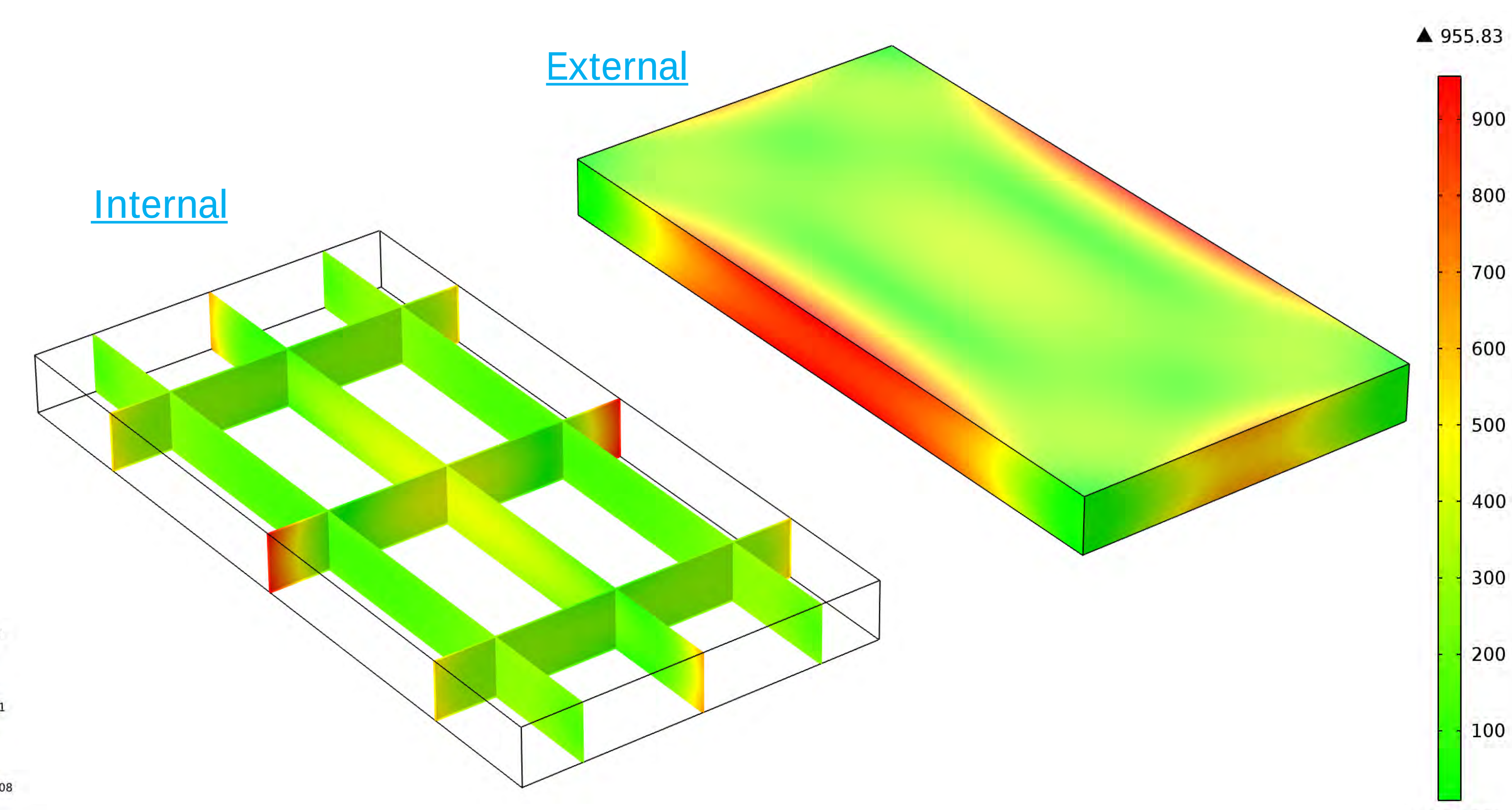

Figure 3. Residual stresses following cooling (External & Internal)

DISCUSSION

A model has been developed to simulate the coupled, interactive transport phenomena between laser, powder, and the substrate during the laser deposition process. The simulation involves laser material & thermal-stress interactions. Controlling the speed & path of the laser dramatically reduces the observed effects, additionally preheating the work piece & constraining it in difference ways drastically change the observed distortion & consecutive build up of residual stresses during manufacture.

CONCLUSION

A transient thermal-stress model describing the powder consolidation of titanium beads using a high powered laser has been developed in a single multiphycsis model. Experimental validation of the observed distortion & residual stresses still needs to be presented, however, the model can be used to better understand the effects of laser speed, path & power on distortion & residual stress.

References:
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3. Yang et al., Comparing the use of mid-infrared versus far-infrared lasers for mitigating damage growth on fused silica, Applied Optics, Vol. 49, No. 14, 10 May 2010.
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