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SUPERPLASTIC FORMING OF 1050 ALUMINIUM ALLOY

Materials Science
Research and Nanotechnology
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AVER CONFERENCES

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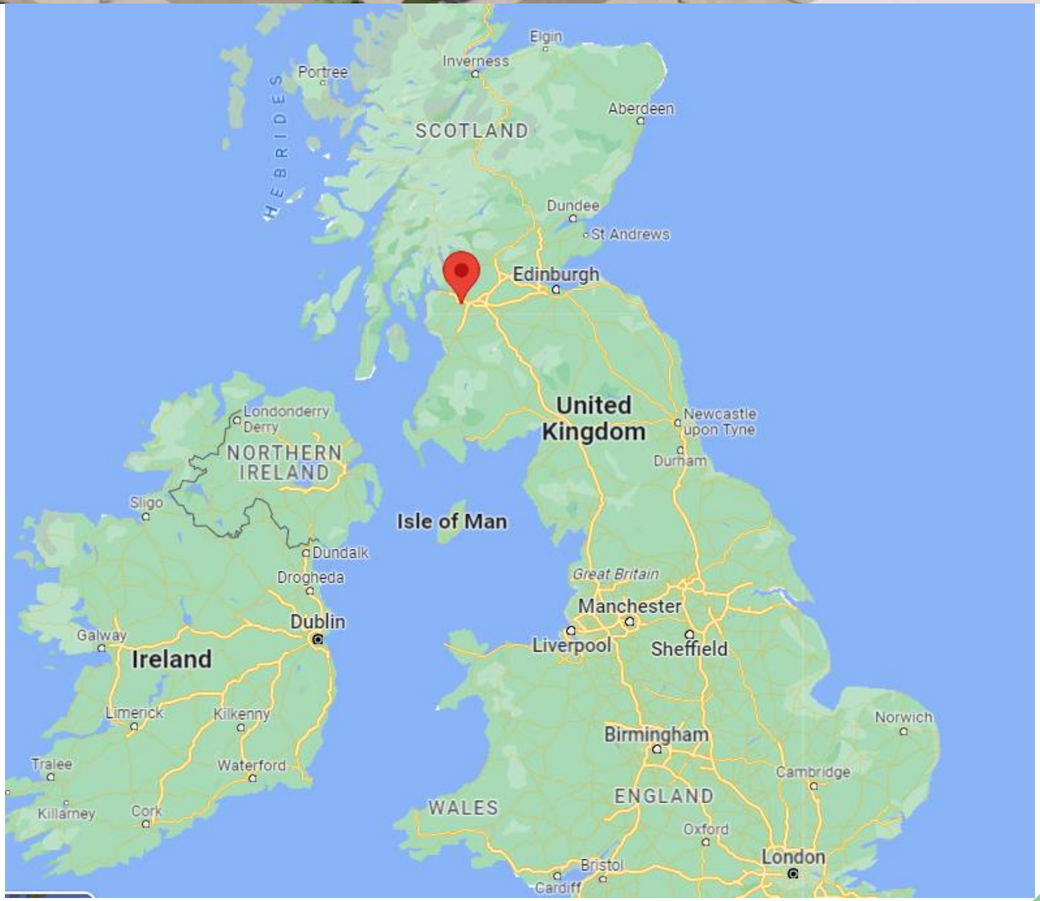
- The National Manufacturing Institute Scotland Group facilities are all located within the Advanced Manufacturing Innovation District Scotland (AMIDS) in Renfrewshire.
- NMIs is a place where industry, academia and the public sector work together on ground-breaking manufacturing research to transform productivity levels, makes companies more competitive and boost the skills of our current and future workforce.
- Our ambitions are to:
  - Increase productivity by reducing barriers to innovation
  - Grow the economy by galvanising investment and increasing manufacturing competitiveness within Scotland and internationally
  - Catalyse job creation and strengthen supply chain links across the country
  - Provide leadership, build collaborations and enhance capability to influence adaptation and exploit manufacturing opportunities to boost Scotland's transition to a net-zero emissions economy by 2045.



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Introduction

- Superplastic forming (SPF) was implemented to form aluminium alloy 1050H14 (AA1050H14) for industrial applications.
- Aluminum alloy1050 is a relatively cheap and very popular aluminium grades with standard designated of AA1050, or commercial identification of Al1050.
- It has many applications in sheet metal work because of its excellent corrosion resistance, high ductility as well as highly reflective finish, however, it has poor machinability due to its strength.
- Typical industrial applications of AA1050 are in chemical process plant equipment, food industry containers, lamp reflectors, architectural flashings.
- AA1050 has potential application in vehicle industry for its better corrosion resistance in acidic environment in compared to aluminium alloys 5xxx and 6xxx.
- H14 temper is the typical tempering process for commercial AA1050 sheets with AA1050-H14 identification.
  - The temper H14 indicates that work hardening, via rolling process, instead of annealing process was implemented to increase the hardness of rolled aluminium sheets by the half of sheets` initial hardness.
  - The work hardening modifies the strain history of the material, and thereof, results in altering thermo-mechanical properties of the material.
- AA1050-H14 has very good cold workability attribute but it has breaking elongation not more than 12%, which is low for the material properties demands of many industrial products.

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Analytical-Numerical-Experimental Works

Uniaxial tensile (UT) test experiments
- at different temperature
- at different strain rates
- at different atmosphere (air, argon)
- in different rolling direction

Calculating strain rate sensitivity (m-value)

Numbers of ABAQUS numerical simulations were developed by implementing the uniaxial tensile test data in creep law for Bailey-Norton law time hardening and strain hardening governing equations.

pressure cycles from the FEM outcomes.

Several trails to blow out AA1050 sheets into the die cavity by hot gas pressure

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UNIAXIAL TEST EXPERIMENTS

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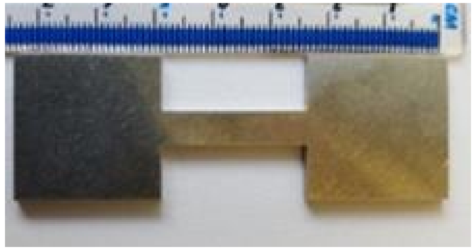
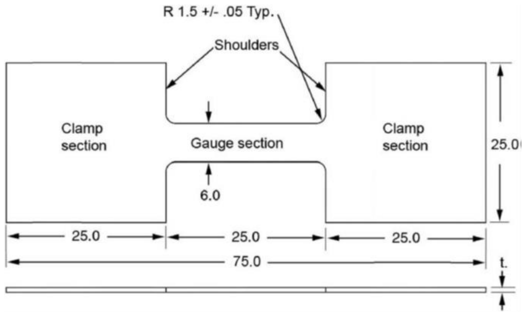
- E 2448-06 standard
- 1050-H14 aluminium alloy sheets in 0^{o}, 45^{o}, and 90^{o} to the rolling direction.
- Wick/Roell Z250 strength testing device
- UT at 200 ^{o}C, 300 ^{o}C, 500 ^{o}C
- Tests were performed at strain rates of 0.001, 0.005, 0.0001, and 0.0005 s^{-1}.
- Tests were performed under argon and air atmosphere





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Stress- Strain curves

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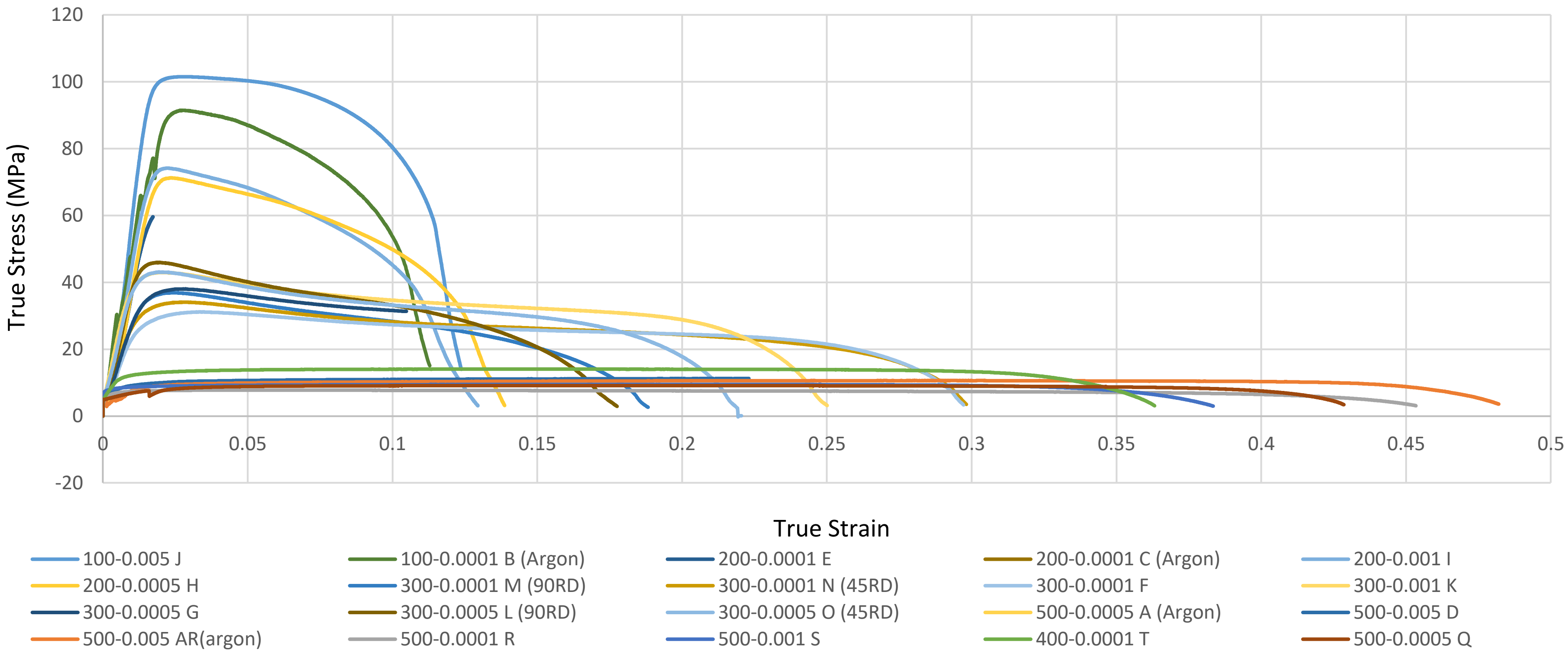
- Uniaxial tensile (UT) test experiments results were scrutinised to obtain the aluminium alloy material behaviour under investigation.



Analysing the effect of strain rate and temperature on the flow stress in AA1050 sheet using E-2448 standard, Allazadeh, M., 30 Nov 2018, In: Journal of Multidisciplinary Engineering Science and Technology . 5, 11, p. 9009-9015 7 p.

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Material model

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- Secondary creep model $\dot{\varepsilon}^{cr} = A\sigma^{m}$

- m-value formulation $m = \left.\frac{\delta \ln \sigma}{\delta \ln \dot{\varepsilon}^{cr}}\right|_{T,\varepsilon}$

- Bailey-Norton law $\dot{\varepsilon}^{cr} = A\sigma^{n} t^{m'}$

- The strain rate sensitivity (m-value) was determined by implementing the uniaxial tensile test data in creep law for Bailey-Norton law time hardening and strain hardening governing equations.
- The m-value of AA1050 was utilised for the models from the previous publication.
- The m-value presented low strain rate sensitivity of AA1050-H14 at 100 ^{o}C, 200 ^{o}C, 300 ^{o}C, and 500 ^{o}C for the selected pure plastic strains before necking zone.

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m-value calculation:

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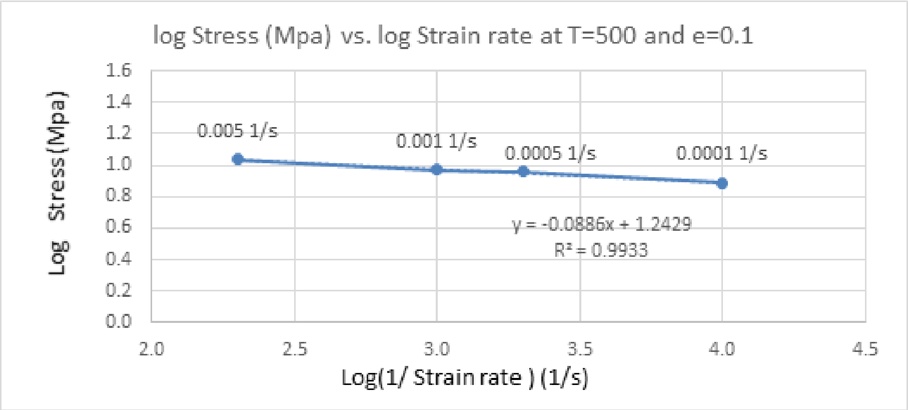

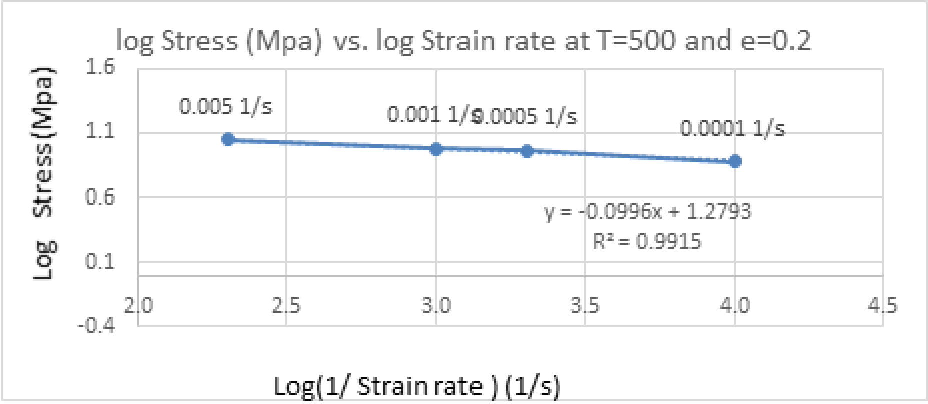

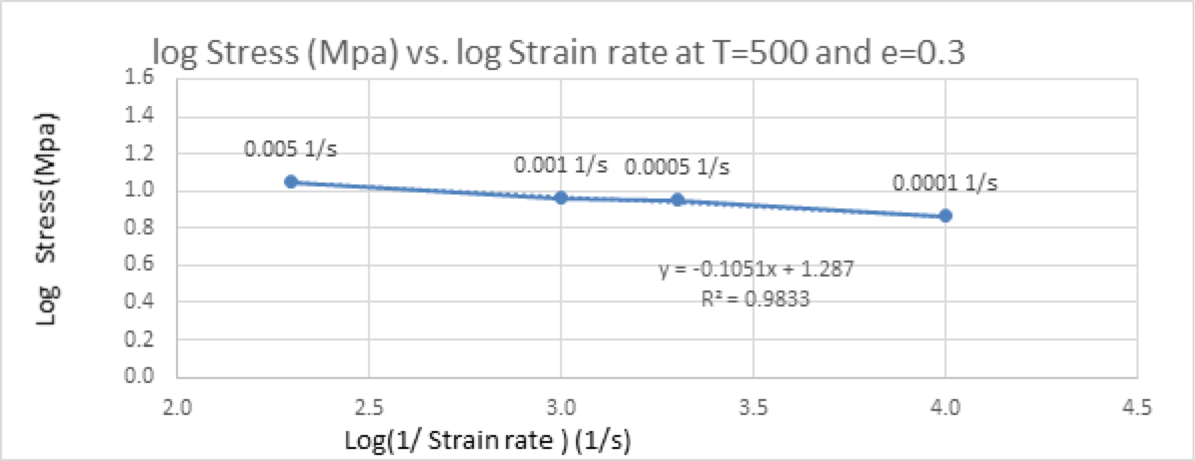

- The maximum m-value for uniaxial tensile tests was found to be about the probe strain of 4% at 300 ºC forming temperature under loading with the strain rate of 0.0005 s^{-1}.

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Allazadeh, Mohammad Reza (2020) Computing strain rate sensitivity of aluminium alloy 1050. International Scientific Survey Journal, 3 (2). pp. 9-27. 2. ISSN 2616-5821 (https://www.syniutajournals.com/index.php/ISSJ/art...)

ABAQUS simulations

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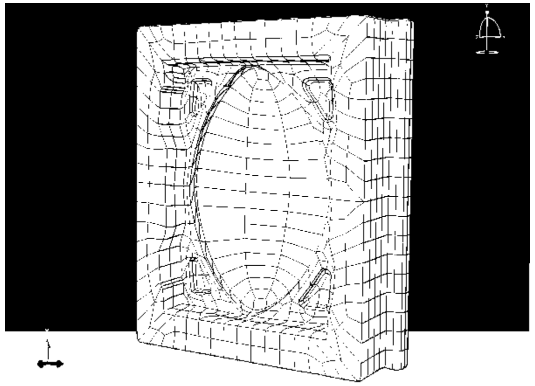
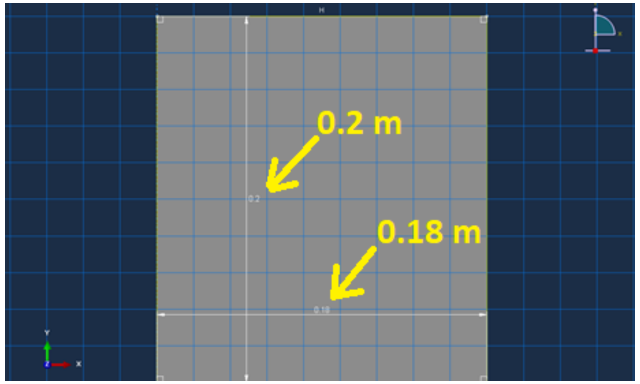
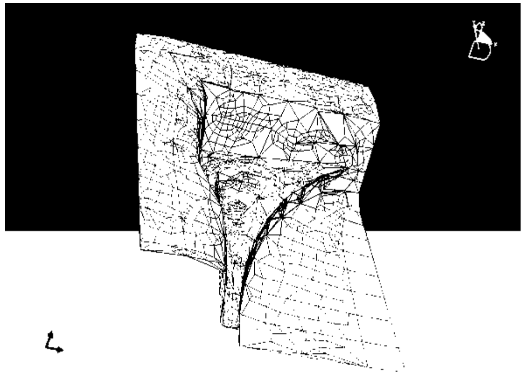
- Numbers of ABAQUS numerical simulations were developed to predict the formation behaviour of the AA1050H14 sheet at different temperature by embedding the built-in creep material model.
- Two numerical methods in ABAQUS /Standard to retain controlled strain for superplastic forming the aluminium alloy sheets via SPF process:

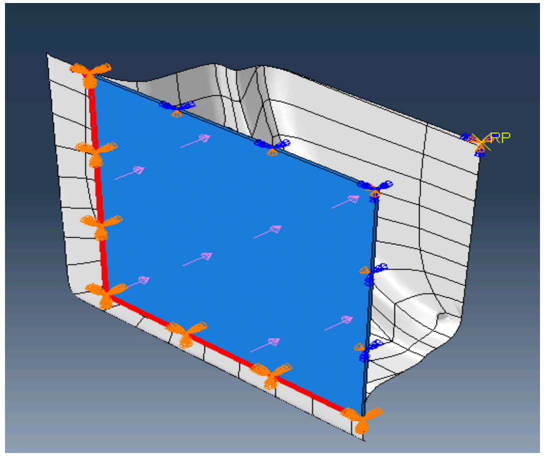
I. tabular amplitude (flow stress),

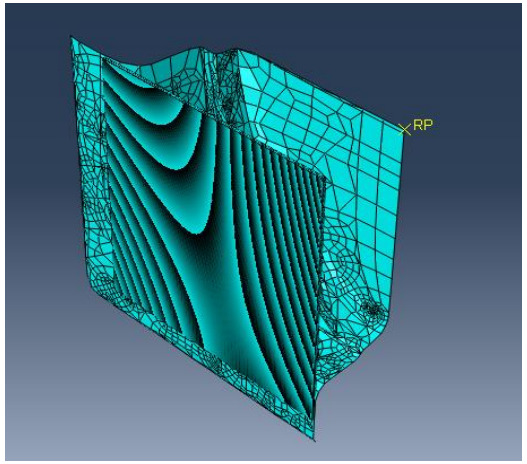
II. and solution dependent amplitude (creep strain rate).











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Full part simulation-Al1050

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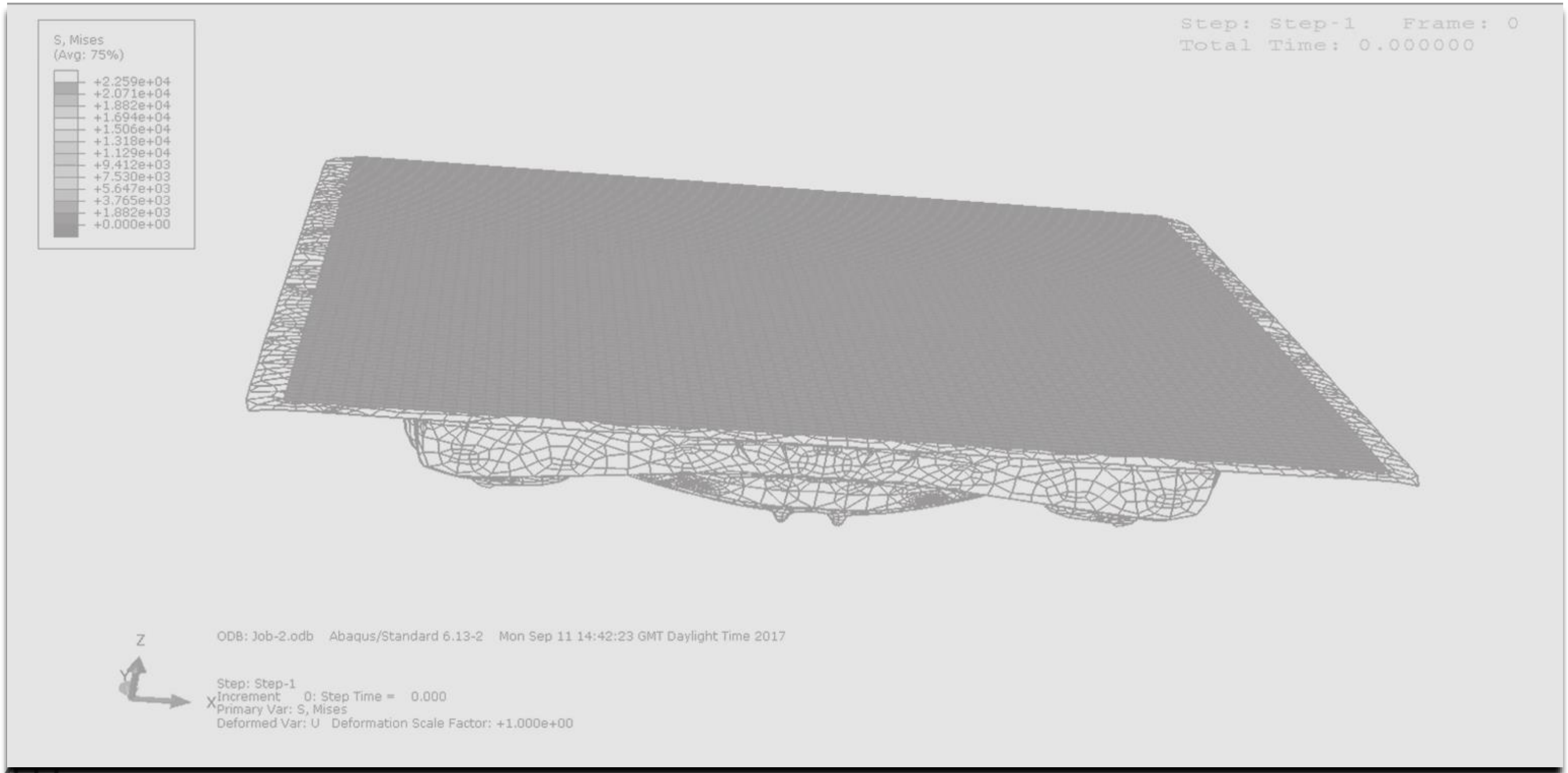

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Al1050 Trials

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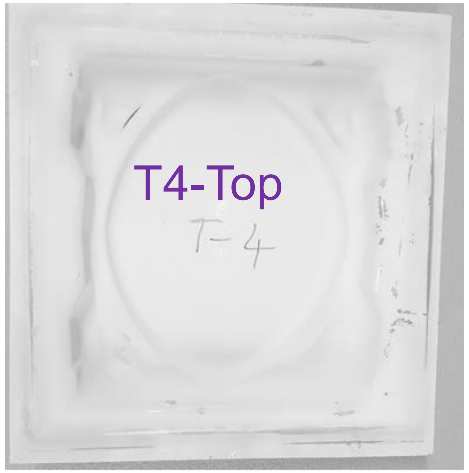
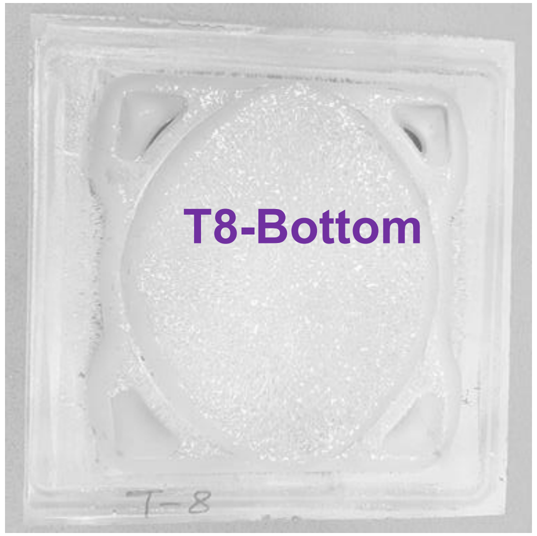
- The AA1050 sheets were blown into the die cavity by hot gas pressure according to the extracted pressure cycles from the FEM outcomes.





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An example of comparison of the trial with the FEM simulation

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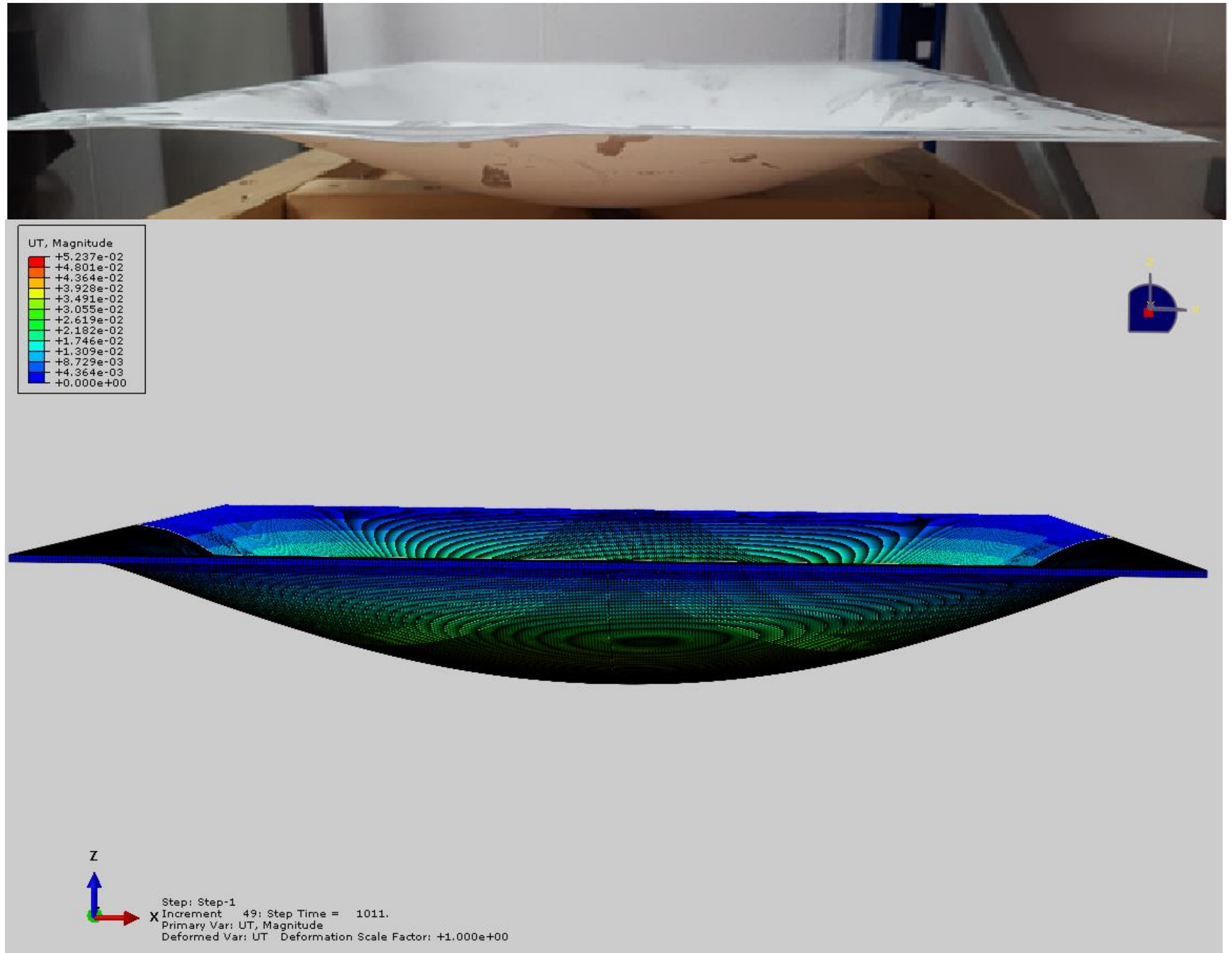
Stopping the formation after 19 minutes



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Correlation on time and shape

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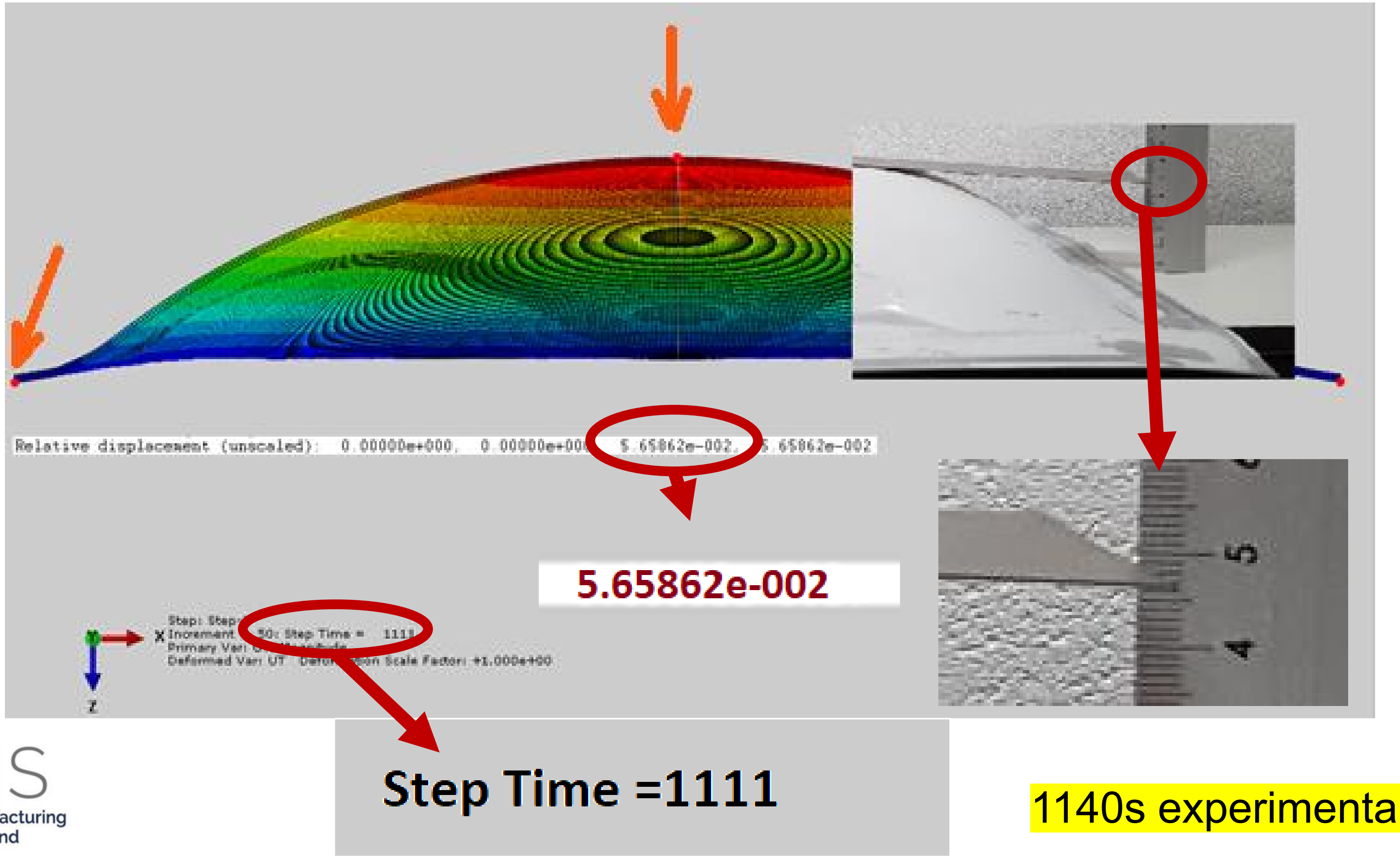

1140s experimental time

Conclusions

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- The material properties of the uniaxial tests for some of the samples were selected for the numerical models.
- Three-dimensional FEM simulations were developed for SPF simulation in ABAQUS for the selected samples by introducing their flow stress curve and m-value in the built-in creep material model.
- The FEM results were analysed to define the pressure cycle required to form the Al1050H14 sheet against cavity of the die set under the target testing conditions (i.e. temperature, strain rate, etc.).
- The ABAQUS simulation results for formation of the sheet part was compared with the formed part by the SPF trial from.
- The outcome of the analysis validated the material flow rate defined by the numerical computation for both aspects of geometrical of the formed sheet and the SPF formation time.
- The ABAQUS results demonstrated that the flat sheets should have capability to present at least 50% strain under 9 MPa loading to be able to make the full formation for the used die in this project.
- It was also observed that the slop of the loading increment is higher for the forming with larger strain rate target.
- It can be concluded that the lead time for SPF forming AA1050 may be suitable for complex boxes used in food packaging industry or relevant sectors.

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