Thermo-viscoplastic behavior of AA7020-T651 in application for modeling of dynamic loadings

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Introduction

The proposed study presents discussion on the behavior of the rolled AA7020-T651 aluminum at a various range of strain rates and temperatures. In order to understand the mechanisms occurring in a material subjected to complex loadings, it is necessary to know its mechanical properties and conditions leading to failure. The determined models constants may be useful for an evaluation and development of lightweight and cost-effective engineering systems.

Material description

The AA7020-T651 belongs to a group of Aluminum Zinc Magnesium ternary alloys. The major alloying element in 7xxx series is Zinc, Magnesium and a reduced percentage of other elements are added to obtain a higher strength. Higher strength 7xxx aluminum alloys exhibit reduced resistance to stress corrosion.

In this study, the investigated aluminum alloy was delivered as rolled plates, tempered and aged in T651 conditions (defined in European Standard NF EN 515). To investigate the behavior of AA7020-T651, several tests were performed under various loading conditions in a quasi-static and dynamic range of strain rates. To eliminate the effect of sample geometry, the material response is given by the true strain – true stress relations. For all curves resulted from compression and tension, the Young modulus is found to be 70 GPa.

The results of the compression test performed at various strain rates are given in Fig. 1(a). The results of a dynamic compression test are obtained using the technique of the split-Hopkinson pressure bar. Each curve is an average curve resulting from 3 tests for an imposed strain rate and temperature. Comparison between curves, resulting from quasi-static and dynamic compression tests, indicates that the investigated Al alloy is moderately rate-sensitive.

Basing on the summarized results, it can be noticed that the material is not much sensitive to the rate of compressive loading. Additionally, the data presented in Fig. 2(a) are completed by the results of the Taylor impact test. The results of the Taylor impact test allow us to observe the behavior of AA7020-T651 for strain rates greater than 10^4 s^{-1}.

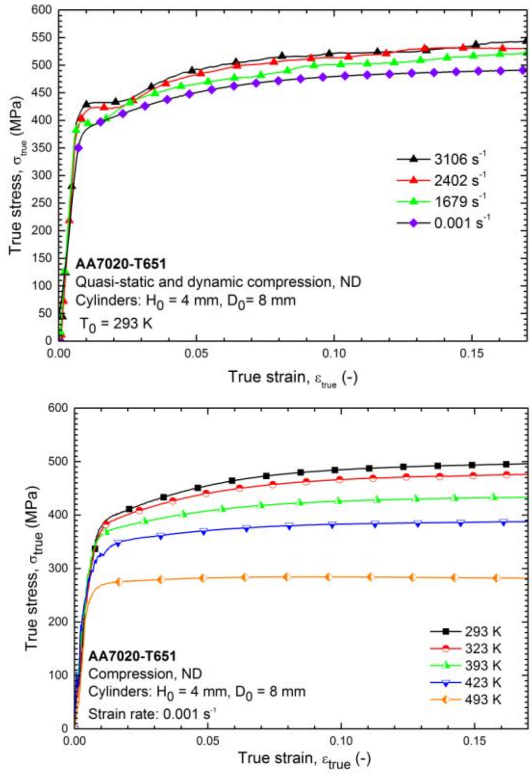

Fig. 1. (a) True stress vs. true strain curves resulting from quasi-static and SHPB compression tests. (b) True stress vs. true strain curves at various temperatures.

Low strain rates have a minor influence on the flow stress and the stress is a linear function of strain rates. After the point of transition, which in the case of the discussed material occurs for a strain rate close to 1500 s^{-1}, the strain rate sensitivity increases rapidly and the slope change becomes positive and much more pronounced. Increasing the temperature leads to a decrease of stress values when the loading is quasi-static. This effect is stronger at higher temperatures. A reduction in the flow stress is more distinct when the temperature increases from 373 K to 473 K; while, for lower temperatures, the flow stress decrease is less significant.

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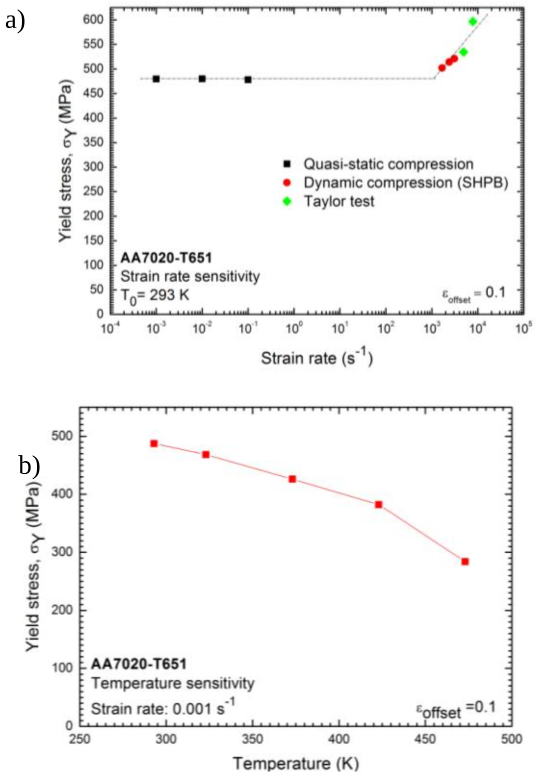

Fig. 2. (a) Strain rate sensitivity and (b) temperature sensitivity of AA7020-T651.

Numerical simulation

To verify the material model - i.e. *MAT_MODIFIED_JOHNSON_COOK, the uniaxial tensile and compression tests are simulated using the LS-DYNA explicit formulation (with a scaled mass to avoid a prolonged time of calculations). Such a model validation based on simple loading cases proves that the material model is able to reproduce a more complex material behavior. A comparison between numerical and experimental results is presented in Fig. 3(a) - (d). It can be concluded that the numerical results are within the accepted accuracy when compared to the experimental curves. The material model calibration is a final step before the model parameters are input into calculations of more complex load cases.

Conclusions

The mechanical and micro-structural properties of AA7020-T651 have been identified and described. Based on the material tests, the constitutive relation and the fracture criterion – the Johnson and Cook models have been determined. The flow and fracture models are implemented in *MAT_107 of Ls-Dyna explicit Lagrangian code. The models describe the material flow and fracture behavior as a function of the strain rate and temperature and it accounts for the damage accumulation in a deforming material. The models have been validated basing on the uniaxial stress modes with a sufficient agreement with the experiment results. Such prepared constitutive relations may be applied in calculations of complex loading modes. Properly determined, calibrated and validated material models are a basis for reliable predictions of materials behavior.

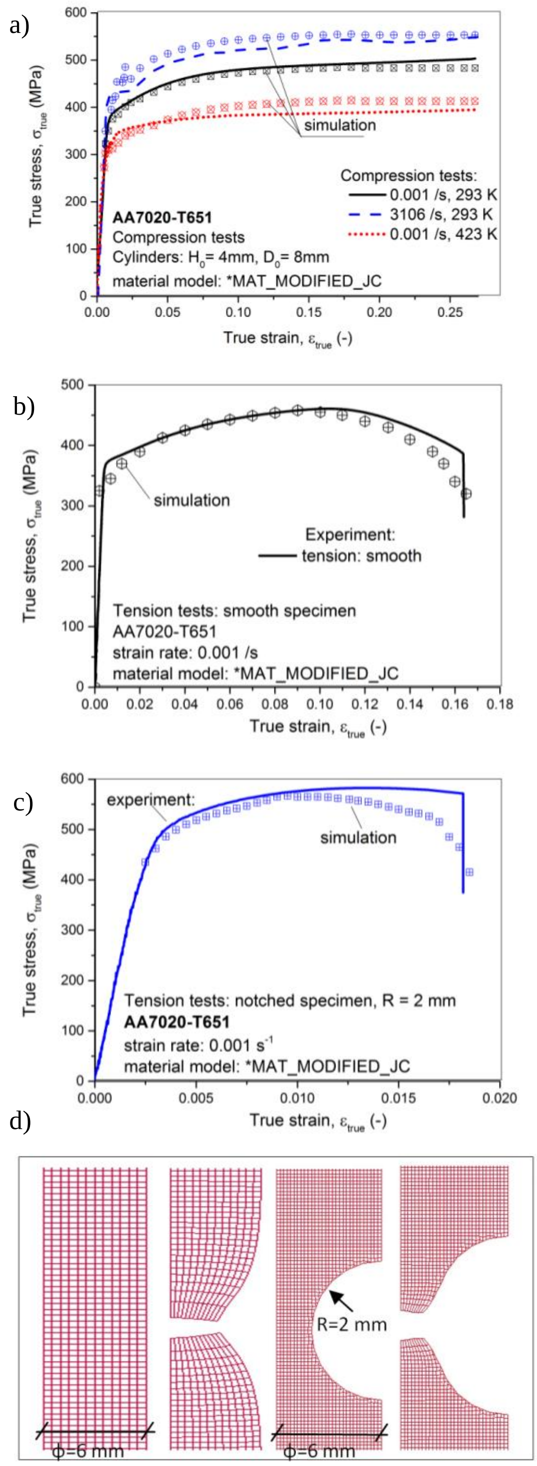

Fig. 3. Comparison between experimental and numerical curves for (a) the compression tests and the tension test for (b) the smooth sample and (c) for notched sample. (d) Details of an initial and deformed mesh of the smooth and notched specimens.