Effect of hardening on toughness: stress-dependent nucleation in the case of 6061 aluminum

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ABSTRACT

A deterioration of fracture toughness, especially of tearing modulus, with aging time and associated strength increase is observed for aluminum 6061 [1] and reproduced here numerically thanks to a new stress based damage nucleation criterion.

Indeed, a correlative multiscale analysis by Scanning Electron Microscopy, Atom Probe Tomography as well as 3D X-ray laminography shows that coarse precipitation and the characteristic damage mechanisms do not depend on aging time: the fracture mechanism is typically ductile and transgranular as shown by EBSD analyses of sections of CT specimens containing interrupted cracks. Large Mg_2Si inclusions fracture at very low plastic strain, and defects nucleate at large (Fe,Si)-rich inclusions with increasing plastic deformation. Only the hardening nanoprecipitation increases with aging time: aging favors precipitation of nano-size Mg_2Si precipitates which cause hardening of the matrix so that damage nucleation at coarse inclusions becomes easier - thus leading to a decrease in toughness.

Based on these observations, a Gurson-Tvergaard Needleman type model is proposed to simulate the database using the Finite Element Method. It uses damage nucleation kinetics which depend on the maximum principal stress, since a classical strain-dependent nucleation is not sufficient to reproduce the deterioration of the tearing modulus. The new stress based damage nucleation law allows to capture sucessfully the experimental trends.

REFERENCES

[1] T. Petit, C. Ritter, J. Besson et T. F. Morgeneyer "Impact of machine stiff ness on 'pop-in' crack propagation instabilities". Engineering Fracture Mechanics, Vol. 202, pp. 405-422 (2018).