CHARACTERIZATION OF MICROSTRUCTURE AND FRACTURE BEHAVIOUR OF 7050 ALUMINIUM ALLOY AFTER HOT FORMING BY MEANS OF CHARPY IMPACT TESTING

D. Pöschmann [1], Ch. Henkel [2], R. Pippan [3], P.J. Uggowitzer [4]

[1] LKR Leichtmetallkompetenzzentrum Ranshofen GmbH, P.O. 26, 5282 Ranshofen, Austria
[2] AMAG rolling GmbH, P.O. 32, 5282 Ranshofen, Austria
[3] Erich Schmid Institute of Materials Science, Austria Academy of Science, Jahnstrasse 12, 8700 Leoben, Austria
[4] Department of Materials, Laboratory of Metal Physics and Technology, ETH Zürich, 8093 Zürich, Switzerland

ABSTRACT

In this study a test procedure is presented, which allows a systematic investigation of the hot rolling process of a 7xxx aluminium alloy. The influence of forming parameters (true strain, strain rate and temperature) on the microstructure is typically investigated by hot compression tests. However, these samples are normally too small for LEFM fracture toughness measurements. Therefore the geometry and the dimension of the hot compression test specimen were adjusted to a miniaturized Charpy specimen that can easily be used for the characterization of the fracture behaviour.
In a first investigation the correlation between fracture toughness and Charpy impact energy of 7050 aluminium plates in different overaged conditions were measured. The results prove the capability of the Charpy impact test for an assessment of the fracture behaviour.
In a second step the hot compression tests were carried out using various hot forming parameters, which cover real conditions during industrial processing. Detailed microstructural analysis together with the results of Charpy impact tests allows quantifying the effect of hot forming parameters on the fracture behaviour of a 7050 aluminium alloy.

KEYWORDS

7xxx aluminium alloy, microstructure, fracture toughness, Charpy impact testing

INTRODUCTION

The high strength 7050 aluminium plate alloy is widely used for thick section products in structural aircraft applications, where fracture toughness and yield strength are important properties [1]. The industrial production involves various processing steps, including casting, homogenization, preheat, hot rolling, solution heat treatment and artificial ageing.
It is known that the microstructure after the hot rolling process has a major influence on the mechanical properties, especially on the fracture toughness. For instance, the fracture toughness decreases with an increase in the degree of recrystallization [2]. Therefore, there is a strong need to systematically study the influence of thermomechanical processing parameters on the evolution of the microstructure, and the resulting properties.
A standard determination of fracture toughness in accordance to the current specifications is only possible at relative large CT-samples (1.5 to 2.0 CT). The material has to be stress relived to achieve valid pre-cracking. This means that a systematic investigation of the

influence of hot rolling parameters on microstructure and fracture behaviour can be performed only using industrially produced material.
The influence of hot forming parameters (true strain, strain rate and temperature) is typically investigated by hot compression tests, HCT. However, due to load restrictions the HCT sample size is limited. It normally only permits the examination and characterization of the microstructure, but not the evaluation of fracture toughness data. Yet it would be very desirable to understand how the microstructure affects the fracture behaviour, or in other words, to get additional information about the mechanical properties out of hot compression test specimens.
These needs make it necessary to find a practical testing procedure that provides a reliable quantification of the material's toughness on sub-sized fracture specimens instead of standard ones. The idea is to apply Charpy impact testing on miniaturized Charpy specimens machined out of HCT specimens. A number of investigators dealt with the correlation between impact energy and fracture toughness, mostly on steels, and show that it is possible to obtain qualitative information from fatigue pre-cracked Charpy specimens [3-6].
The aim of the presented work is to introduce a test procedure for 7xxx aluminium plate alloys, which allows a systematic investigation of the influence of hot forming parameters on the fracture toughness.

EXPERIMENTAL

The investigated material was a 7050 aluminium alloy provided by Austria Metall AG, which was rolled to 76.2 mm thick plate, solution heat treated, water quenched, and stress relieved. The material was machined into blanks with the size of 250 mm x 250 mm x 76.2 mm and subjected to different artificial aging conditions in a laboratory air-circulation furnace. A one-step aging treatment was applied to reach the peak-aged condition and a two-step aging for overaged conditions. The base material condition was "natural aged".

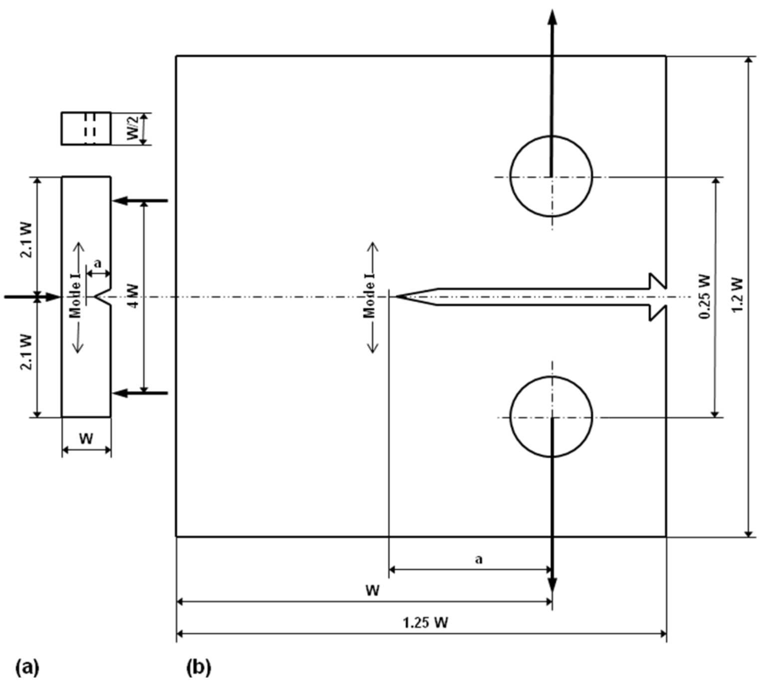


Fig. 1: Schematic illustration of miniaturized Charpy specimen (a) and compact tension specimen (b) used for fracture toughness tests with characteristic dimensions

Fig. 1 shows the specimen geometry of the miniaturized Charpy specimen and the compact tension specimen used for valid fracture toughness tests. Both specimens were machined in the same fracture plane out of the plate material. The determination of fracture toughness was carried out in accordance to ASTM E 399 using 1.0 CT-samples. The design of the miniaturized Charpy specimen was based on ASTM standard three-point bending specimen [7]. The cross section of the chosen specimens was 6 mm x 3 mm and the length 30 mm.
The notch was eroded with a radius of 0.1 mm and subsequently pre-cracked under cyclic compression. This is the most efficient way to produce a sufficiently sharp crack with a defined crack length [8,9]. The tests were performed at a stress ratio of R=20; the crack length measured from the notch root was adjusted to 0.2 – 0.4 mm.
Cylindrical compression specimens with 37 mm in diameter and 55 mm in height were machined from homogenized 7050 ingots. The hot compression tests were performed on an instrumented servo-hydraulic testing machine. The specimens were heated to the test temperature and compressed with constant true strain of 0.6 in 1, 2, and 4 forming steps to simulate the reverse hot rolling process; strain rates of 0.01, 1 and 10 s^{-1} were used. After the forming procedure the compression specimens were air-cooled to room temperature.
The samples for metallographic analyses were sectioned from the specimen centre, polished and etched using Dix-Keller agent for optical microscope observation.
Both, fracture toughness tests and Charpy impact testing were carried out in the L-T, T-L and S-L orientation for the rolled and heat treated plate. For the various “hot compression conditions” only Charpy impact testing in L-T and S-L orientation was used (sectioned from the specimen centre). Because of the rotation-symmetric shape of the HCT-specimens a differentiation between sample orientation L-T and T-L was no longer relevant. Therefore all samples parallel to the radius were specified as a L-T-orientation. Additionally, the corresponding tensile specimens in L- and ST-direction with 3 mm in diameter and 30 mm in length were machined out of the hot compression specimens.

RESULTS

Heat treatment experiment

Table 1 shows the fracture toughness and Charpy impact energy data for L-T, T-L and S-L orientation for the alloy 7050 in various hardening conditions. For both data sets, fracture toughness and impact energy, significant orientation dependence can be observed. Interestingly, the ranking between T-L and S-L orientation is different for fracture toughness and impact energy values. The impact energy values decreases in the order L-T, T-L and S-L, while the fracture toughness values decreases in the order L-T, S-L and T-L.
In natural aging condition the highest fracture toughness is observed. The slight overage condition 3 results in the lowest values, which increases with increasing aging time as expected.

condition	heat treatment	fracture toughness [MPa√m]			impact energy [Nm]		
		L-T	T-L	S-L	L-T	T-L	S-L
1	natural aged	42.27	36.12	39.69	1.150	0.608	0.442
2	peakaged	30.76	25.49	27.94	0.681	0.363	0.292
3	overaged	26.96	23.23	25.45	0.675	0.250	0.217
4	overaged	30.16	25.12	26.52	0.806	0.350	0.283
5	overaged	35.67	28.46	29.73	1.044	0.469	0.367
6	overaged	39.04	30.56	31.92	1.267	0.613	0.567

Tab. 1: Fracture toughness and impact energy after different aging treatments of alloy 7050

The empirical relation between fracture toughness and notch impact energy after different aging treatments is shown in Fig. 2 (note: the more physical-relevant term K_{IC}^2/E was used). Obviously, there is a good linear correlation for the artificial aging conditions. The natural aging condition, however, shows a clear deviation from this relation, especially for the S-L orientation. This indicates that the correlations are restricted to less-ductile fracture behaviour. In summary, the results show, that Charpy impact data can be used for the estimation of fracture toughness data, at least for the artificial aged tempers, which are characterized by high strengths and reduced fracture toughness.

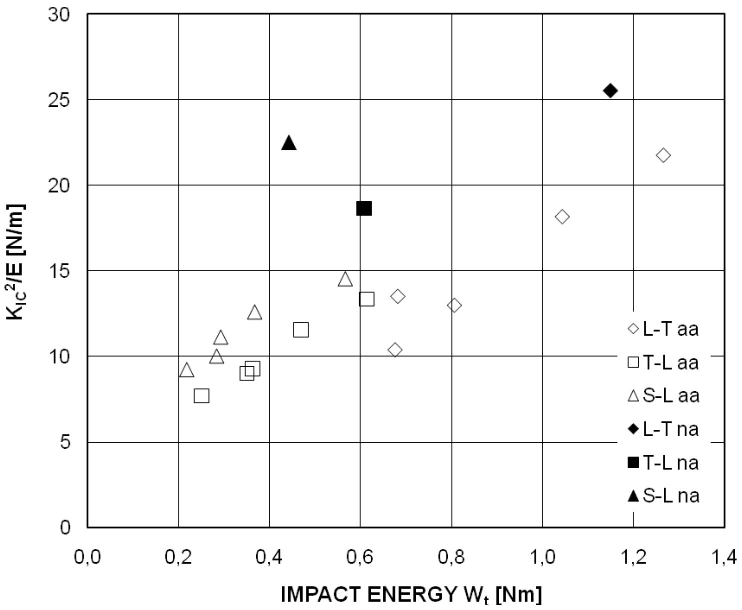


Fig. 2: Empirical relation between fracture toughness and Charpy impact energy for various aging conditions of alloy 7050, (na = natural aged, aa = artificial aged)

Hot compression test

Fig. 3 shows the empirical relation between impact energy and yield strength after hot compression tests with different strain rates (0.01, 1 and 10 s^{-1}) and forming steps (1, 2, and 4) at constant true strain of 0.6.
Obviously, the parameter combination with a strain rate of 10 s^{-1} and 4 forming steps, which results in the lowest value of yield strength and only average impact energy, does not lead to desired results. There is no possibility to improve the toughness by overaging, because the yield strength is near the specified lower limit. The compression test at strain rate of 1 s^{-1} in 2 forming steps reaches the highest value of impact energy at average yield strength level. The highest yield strength was reached by the parameter combination with a strain rate of 0.01 s^{-1} and 2 forming steps. This condition holds the potential for increasing impact energy by means of overaging with acceptable loss in yield strength.

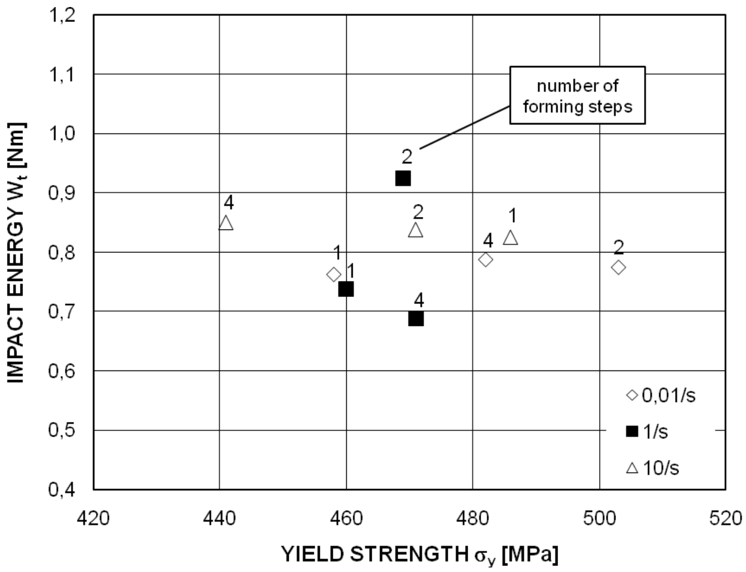
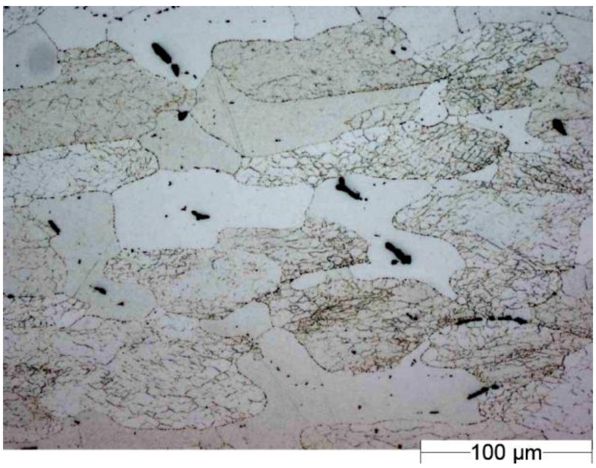


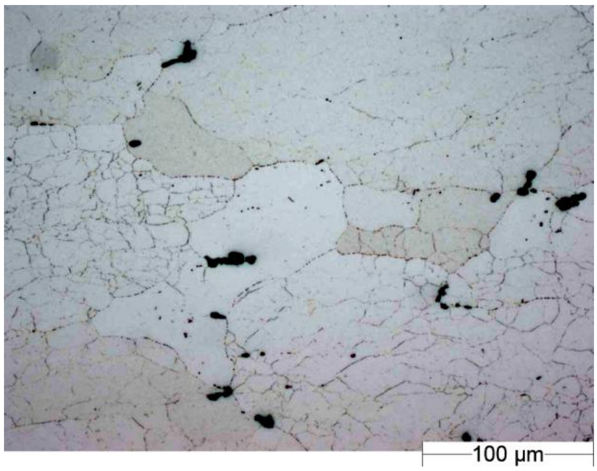
Fig. 3: Relation between impact energy and yield strength after hot deformation test with different strain rates of 0.01, 1 and 10 s^{-1} and forming steps of 1, 2, and 4 by constant true strain of 0.6 of alloy 7050

The microstructures near the fracture surfaces of the Charpy specimens are shown in Fig. 4 for a strain rate of 1 s^{-1} (a) and 0.01 s^{-1} (b) compressed in 2 forming steps. The sample with a strain rate of 1 s^{-1} is partially recrystallized, with a small sub-grain size. It exhibits the highest impact energy, which is in agreement with findings reported in literature [2]. The sample with a strain rate of 0.01 s^{-1} shows a higher degree of recrystallization (needs to be checked by means of EBSD measurements). Interestingly, this condition exhibits the highest yield strength.

Both microstructures feature different combinations of strength and toughness. They exemplarily illustrate the correlation between forming parameters, microstructure and mechanical properties. It is the subject of ongoing investigations to clarify the most important controlling relations.



(a)



(b)

Fig. 4: Optical micrographs of longitudinal section of 7050 alloy compressed in 2 forming steps at different strain rates 1 s^{-1} (a) and 0.01 s^{-1} (b), followed by solution heat treatment and artificial aging

SUMMARY

An empirical correlation between fracture toughness and Charpy impact energy of 7050 aluminium alloy in different overaged conditions were established. The results prove the capability of the Charpy impact test for an assessment of the fracture behaviour.
First hot compression tests were carried out using various hot forming parameters, which cover real conditions during industrial processing. Microstructural analysis together with the results of Charpy impact tests allows quantifying the effect of hot forming parameters on the fracture behaviour of 7050 aluminium alloy.

ACKNOWLEDGEMENTS

The authors would like to thank Austria Metall AG, Ranshofen, Austria for supporting this R&D project and for permission to publish this paper.
The corresponding ForMAT project at LKR Leichtmetallkompetenzzentrum Ranshofen GmbH was sponsored by the European Regional Development Fund as part of the EU programme “Regional Competitiveness OÖ 2007-2013 (Region 13)” and by the province of Upper Austria.

LAND OBERÖSTERREICH

REFERENCES

[1] Starke Jr., E.A., Staley, J.T., Application of modern aluminium alloys to aircraft, Progress in Aerospace Sciences, Vol. 32, pp. 131-172, 1996
[2] Deshpande, N.U., Gokhale, A.M., Denzer, D.K., Liu, J., Relationship between fracture toughness, fracture path, and microstructure of 7050 aluminum alloy: Part I. Quantitative characterization, Metallurgical and Materials Transactions A, Vol. 29, No. 4, pp. 1191-1201, 1998
[3] Schindler, H.J., Morf, U., A closer look at estimation of fracture toughness from Charpy V-notch test, International Journal of Pressure Vessels and piping, Vol. 55, Issue 2, pp. 203-212, 1993
[4] Schindler, H.-J., Abschätzung von Bruchzähigkeitskennwerten aus der Bruch- oder Kerbschlagarbeit, Materialwissenschaft und Werkstofftechnik, Vol. 32, No. 6, pp. 544-551, 2001
[5] Kim, S.H., Park, Y.W., Kang, S.S., Chung, H.D., Estimation of fracture toughness transition curves of RPV steels from charpy impact test data, Nuclear Engineering and Design, Vol. 212, Issus 1-3, pp. 49-57, 2002
[6] Heerens, J., Ainsworth, R.A., Moskovic, R., Wallin, K., Fracture toughness characterisation in the ductile-to-brittle transition and upper shelf regimes using pre-cracked Charpy single-edge bend specimens, International Journal of Pressure Vessels and piping, Vol. 82, Issue 8, pp. 649-667, 2005
[7] Schneider, H.-C., Entwicklung einer miniaturisierten bruchmechanischen Probe für Nachbestrahlungsuntersuchungen, Forschungszentrum Karlsruhe, FZKA 7066, 2005
[8] Pippan, R., The growth of short cracks under cyclic compression. Fatigue & Fracture of Engineering Materials & Structures Vol. 9, No. 5, pp. 319-328, 1987
[9] Pippan, R., The length and the shape of cracks under cyclic compression: the influence of notch geometry. Engineering Fracture Mechanics Vol. 31, No. 4, pp. 715-718, 1988

Corresponding author: daniel.poeschmann@ait.ac.at