Fracture Toughness Depending on Compounded Structure of Materials.

K. DETERT*, K. BECKER** and K. D. GINSBERG***
**Universität – GH – Siegen, Institute für Werkstofftechnik Paul – Bonatz Str. 9–11, 5900 Siegen, FRG*
***AEG—Telefunken, Institute für metallische Werkstoffe Goldsteinstr. 235, 6000 Frankfurt 71, FRG*
****Hess—Maschinenfabrik Im Scheidt, 5909 Burbach, FRG*

ABSTRACT

Fracture was studied on compound-specimens made from sheets of high strength alloys such as age hardened AlZnMgCu alloy or 18 percent Ni maraging steel. It was investigated at which sheet-thickness one could expect the highest value of fracture toughness. One could demonstrate that fracture toughness had a maximum value when the sheet thickness was about 0.3 mm for the agehardened Al-alloy but 1.9 mm for the Ni-maraging steel. The investigations were also performed on compounds made from sheets of the same material containing circular holes. In the compound specimens made of sheets with holes the fracture toughness increased with the diameter of the holes, the thickness of the sheets and the distance between the holes. By a deliberate choice of parameters it was possible to increase the value of fracture toughness to more than twice the value measured of massive specimens from the same alloy.

KEYWORDS

thickness effect, fracture toughness, notch root radius, laminates

INTRODUCTION

In order to utilize high strength alloys for aircraft and space applications a favorable combination of high mechanical strength and fracture toughness is required. There exists a possibilty to improve the fracture toughness of a component without loosing the necessary strength by using a composite instead of a massive part. An investigation was performed to study the possibility of improving the fracture toughness by fabricating flat parts from sheets adhered by adhesives.

It is well known that the fracture toughness inreases wenn the sheet thickness decreases (Bluhm, 1961). According to Irvin (Irvin, 1968) one has postulated a certain thickness, where fracture toughness has its maximum value. From those results one can derive that a compound made from sheets might also have a higher fracture toughness than a massive part.

Furthermore one knows that fracture toughness of a specimen which contains a crack can be improved when the cracktip is marked by a hole. But fracture toughness is also improved when the hole is made in the neighborhood of a cracktip (Tetelman et al, 1971) . From those results one can derive, that a sheet which contains holes will show a higher fracture toughness, depending on the diameter and the distance of the holes compared to sheets without holes.

The investigations, which will be reported here, deal with the methods how to improve the fracture toughness of two different high-strength alloys, as mentioned above, in order to define the exact values for fabricating parts of components, where high strength with an optimum of fracture toughness is required. The one alloy was the agehardened high strength alloy AlZnMgCu1.5 or A7075 the other one was the 18 percent Ni-Maraging Steel X2NiCoMo 18 9.

EXPERIMENTAL PART

From the Al-alloy, sheets were manufactured by hot and cold rolling to a thickness of 0.38 , 0.5 and 1.5 mm and then agehardened by a solution anneal at 470°C quenching in water and aging at 125° for 12 to 14 hrs. The chemical analysis is given in table 1. The mechanical properties are shown in table 2. For fabricating a composite the sheets were pasted together by a two component adhesive made from polyurethan.

Table 1. Chemical Composition of AlZnMgCu 1.5 in wt percent

Si	Fe	Cu	Mn	Mg	Cr	Zn
0.08	0.18	1.55	0.17	2.36	0.20	5.60

Table 2. Mechanical Properties of AlZnMgCu 1.5

R_m (N/mm²):	600
$R_{p0.2}$ (N/mm²):	545
ϵ_B (%):	14.8
Hardness (BHN)	170

The maraging steel was hot rolled into sheets of 2 and 7 mm. It was further cold rolled to various thickness down to 0.6 mm, solution annealed at 870°C with aircooling and aged for several hours at 480°C. The chemical composition of the different heats are given in table 3. The mechanical properties are shown in table 4. To fabricate the compound an epoxy adhesive (Araldit) was used.

Table 3. Chemical Composition of 18 percent Ni maraging steel

Heat No	C	Si	Mn	Mo	Ni	Al	Co	Ti
1	0.005	0.02	0.02	5.07	17.9	0.10	9.10	1.17
2	0.004	0.02	0.01	5.03	18.2	0.11	9.17	1.20

Table 4. Mechanical Properties of 18percent Ni maraging steel

Heat No	1	2
R_m (N/mm²):	2150	2225
$R_{p0.2}$ (N/mm²):	2050	2180
ϵ_B (%):	3	4
hardness (HRC):	55	55

Tensile strength was measured on flat specimens. Fracture toughness measurements were carried out by specimens according to those being used for fracture-mechanics tests. In general CT-specimens were fabricated, as shown in fig 1. In order to compare the results of different specimens the maximum value of the sustained load is introduced into the calculation of the stress-intensity-factor K using the actual crack-length without correction for the plastic zone size. This value of K connected with the maximum value of load sustained before crack growth is labeled as K_m.

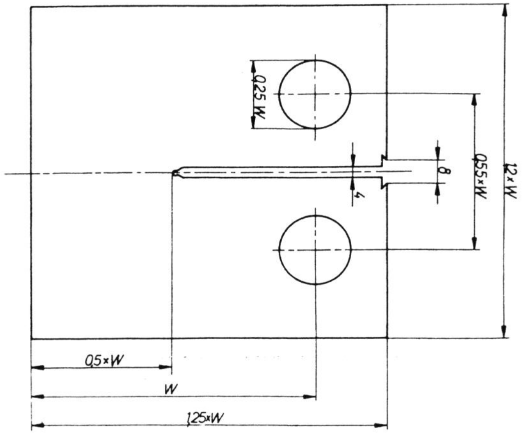

Fig. 1. Compact-Tension (CT) Specimen as fabricated with W = 50 mm. Thickness t = 20 mm.

RESULTS

The influence of the sheet thickness in the CT-compound-specimens on fracture-toughness is shown in fig.2a and b for the two investigated alloys. One can derive from the results that

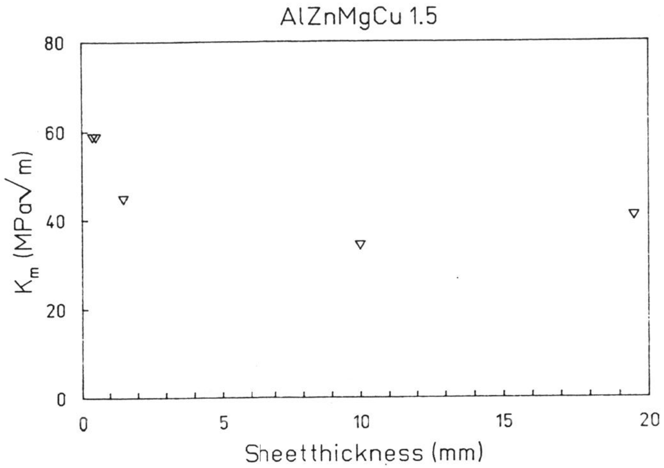

Fig. 2a

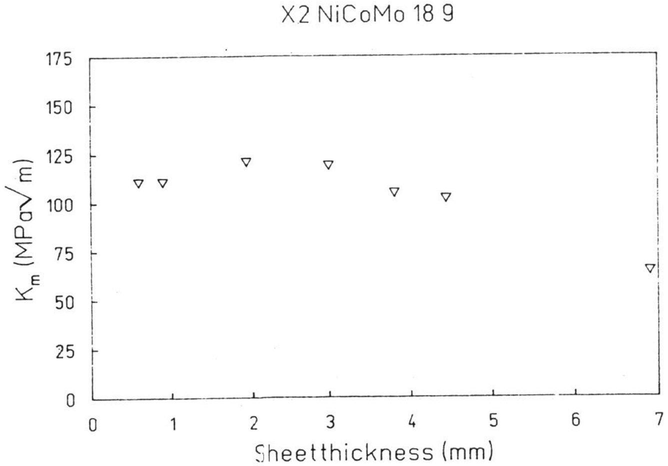

Fig 2b

Fig.2. The influence of sheet thickness on fracture toughness at maximum load K_m.
a.) ALZnMgCu1.5 alloy
b.) 18percentNi-maraging steel

for the aluminium-alloy the minimum sheet-thickness of 0.38mm leads to the maximum value of K_m being nearly twice as high as the value of fracture toughness for massive specimens as measured according to the ASTM rule E 399. In the maraging steel the optimum thickness of the sheets was near 2mm.

Furthermore the influence of notch-radius was studied by introducing a hole at the end of the machined slot replacing the crack as introduced by fatigue at the tip of the slot. The results are shown in fig.3a and b for the different alloys. The results confirm that higher values of K_m are obtained with a larger radius of curvature at the crack-tip.

It is interesting to note that for the sheets with the thickness studied the K_m value was the higher the thicker the sheets. If other holes exist in the neighborhood of the crack-tip the value of K_m was reduced in comparison to a specimen wich contained only one hole at the cracktip. As seen in fig.4a and b, the value of K_m depends on the relation of distance to diameter of the holes. Apparently there exist an optimum value for the relation, when the limit is reached that the crack yet deviates from the plane of the ligament towards the neighboring hole, as shown in the photograph of Fig.5a and b.

DISCUSSION.

The results prove that one can increase the fracture toughness by using compounds of sheets instead of massive material of the same strength. Reducing the thickness of the sheets is one way to increase the fracture toughness. An optimum of sheet-thickness apparently exists, which depends on the material. The equations to derive such optimum of sheet thickness from the mechanical properties, as given by Broek and Vlieger (Broek et al, 1973) and Irwin (Irwin, 1968), are not obeyed. Introducing circular holes in the sheets is another method to increase the fracture toughness. Since the plastic zone size is increased by the hole at the tip of the crack, crackgrowth is stopped by such a hole. The sheet thickness to utilize such an effect can be increased. Since the size of the plastic zone is spread out by a larger radius of curvature at the cracktip, fracture toughness is the higher the larger the radius of curvature (Malkin et al, 1971). The relation of distance to diameter of the holes should not exceed the factor 2.5 in order to provoke the deflection of cracks.

The results have shown that a fracture toughness can be obtained more than twice as high by using compounds of sheets, which may contain holes without loosing the mechanical strength of the massive material.

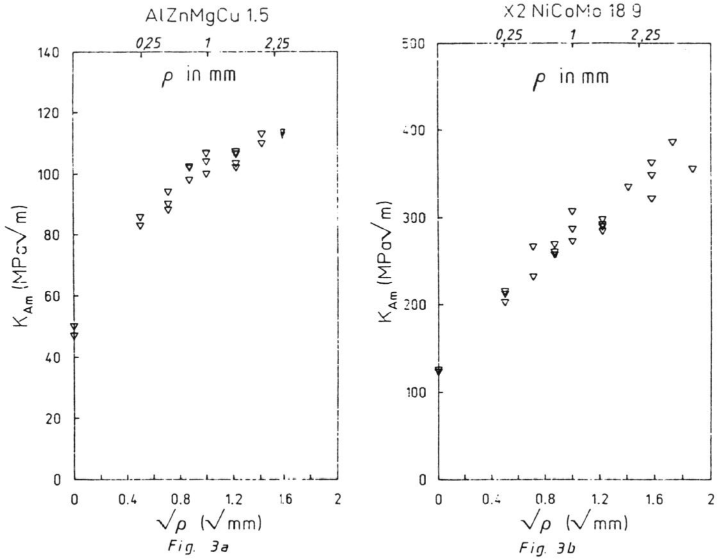

Fig. 3a

Fig. 3b

Fig.3. The influence of notch-radius on fracture toughness K_m
a) ALZnMgCu1.5 alloy (sheet-thickness 1.5 mm)
b.) 18percentNi-maraging steel (sheet-thickness 1.9 mm)

ACKNOWLEDGEMENT

The authors are very gratefull to the financial support which was given by the Minister für Wissenschaft und Forschung des Landes Nordrhein-Westfalen, Germany.

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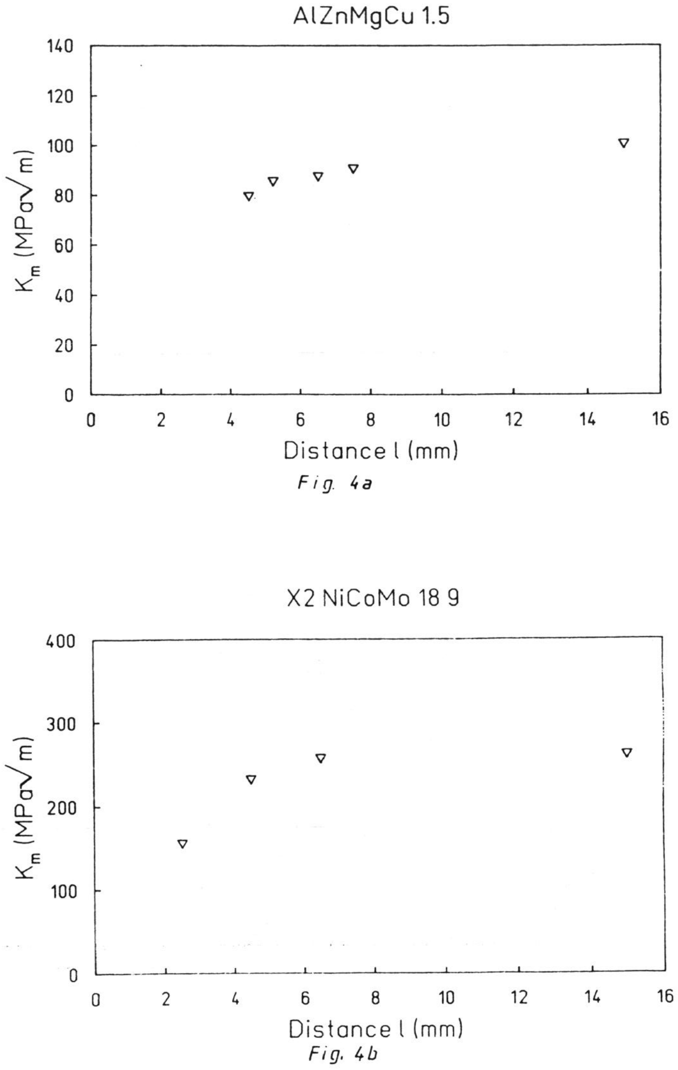

Fig. 4a

Fig. 4b

Fig.4. The influence of distance of holes on K_m (diameter of holes 1.5 mm)
a.) ALZnMgCu1.5 alloy (sheet-thickness 1.5 mm)
b.) 18percentNi-maraging steel (sheet-thickness 1.9 mm)

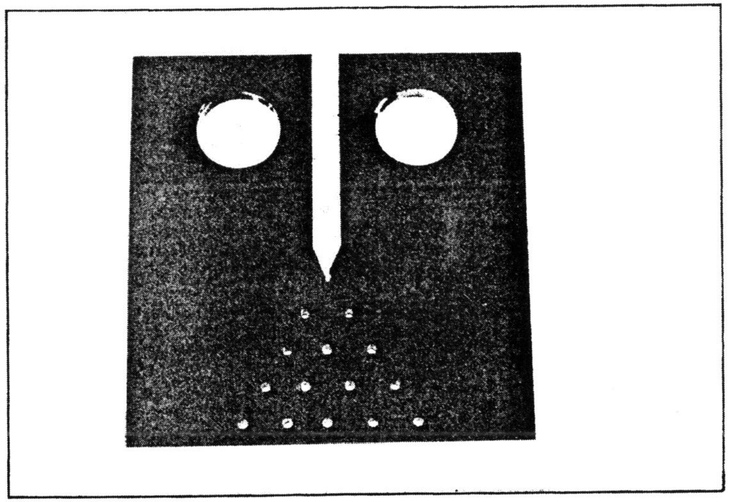

Fig. 5a

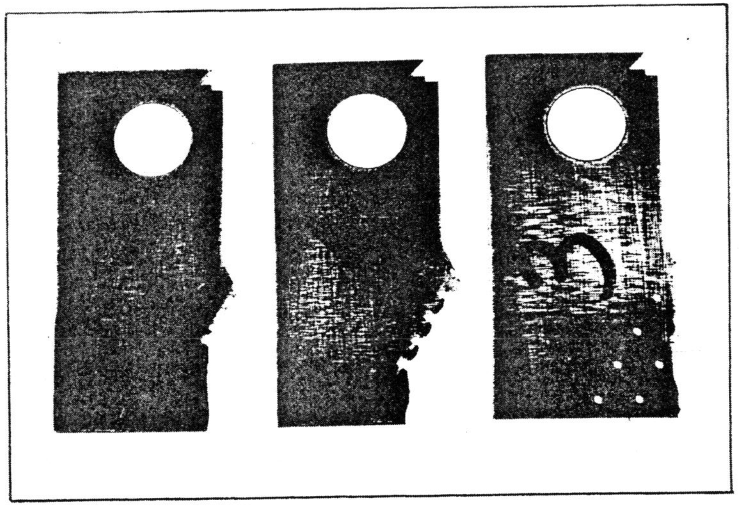

Fig. 5b

Fig.5. Photograph of sheets with holes (diameter 1.5mm) in a CT specimen (18percent Ni-maraging steel)
a.) specimen before the test
b.) specimens after the test with different distance of holes.