CRACK GROWTH CURVES FOR ALUMINIUM WELDMENTS

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ABSTRACT

Information on the crack propagation behaviour of the various material zones of an aluminium weldment is given covering standard structural alloys, typical thicknesses and stress parameters. Comprehensive experimental results allow the development of harmonized relationships between crackpropagation rates and effective stress intensity values.

KEYWORDS

Crack propagation, fracture mechanics, fatigue, aluminium alloys, weldments, effective stress intensity values

INTRODUCTION

In the last years the use of aluminium in structural engineering has reached significant proportions, especially in the field of transportation. Advatageous material properties like low weight, low temperature behaviour as well as an improved fabrication technology integrating complex extrusions joint by welding in sophisticated structural components establish competitiveness of aluminium against other materials.

Due to the ratio between the yield strength and fatigue endurance limit in many structural details in aluminium and in several important applications, as well as due to the stress ratio between dead and life loads in the case of aluminium components a fatigue assessment may often prove to be the critical one. The recently published European Recommendations for Aluminium Fatigue Design [1] form a international milestone in the evaluation of fatigue data and subsequent classification of aluminium structural details. For the first time data from different sources, industry, university and other research institutes were collected, evaluated and harmonized to formulate respective design values [2, 3]. At an other early stage, a fatigue assessment based on fracture mechanics analysis was regarded as a complementary method in the recommendations. Unfortunately due to the fact of a fixed time scedule for the above European Recommendations and the fact that evaluation of respective fracture mechanics data was still in progress, these procedures were not included in the document. Just recently in a Ph.D. by Graf [4] comprehensive material for an array of aluminium alloys, plate thicknesses, R-ratios and for the different regions within a weldment - unaffected base material, heat-affected-zone, weld zone - has been evauated and published. The paper presents the main material characteristics and results of the crackpropagation measurements.

MATERIAL AND TEST SPECIMENS

Three standard alloys used in structural engineering 5083 (AlMg4,5Mn), 6082 (AlMgSi1) and 7020 (AlZn4,5Mg1) were considered. The material came from a single normal production lot. For the 6082 and 7020 alloys extruded plates were produced, for the 5083 alloy rolled plates were used. The chemical composition of the different alloys is shown in Fig.1, mechanical properties are given in Fig.2.

Alloy	t	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr
	mm	%	%	%	%	%	%	%	%	%
5083	4	0,23	0,42	0,034	0,70	4,70	0,12	0,11	0,014	-
	10	0,12	0,31	0,036	0,61	4,62	0,11	0,13	0,011	-
	20	0,23	0,36	0,032	0,63	4,55	0,09	0,10	0,010	-
	30	0,15	0,32	0,042	0,68	4,57	0,09	0,13	0,010	-
6082	4	0,89	0,29	0,03	0,89	0,76	0,01	0,01	0,015	-
	8	0,83	0,26	0,02	0,91	0,80	<0,01	0,02	0,011	-
	17	0,80	0,25	0,02	0,92	0,78	<0,01	0,03	0,011	-
7020	4	0,26	0,25	0,13	0,36	1,40	0,16	4,26	0,017	0,14
	8	0,25	0,23	0,12	0,35	1,38	0,15	4,23	0,015	0,14
	20	0,27	0,27	0,14	0,34	1,36	0,15	4,21	0,013	0,12

Fig.1: Chemical composition of tested alloys

The plates were welded together by butt welds with 5183 (S-AlMg4,5Mn) wire and the overfill was ground flush. Automatic welding was performed with the parameters given in Fig.3.

Alloy	t	Orientation	E-Modul	$R_{p0,2}$	R_m	A_5	R_a
	mm		N/mm²	N/mm²	N/mm²	%	%
5083	4	T-L	77500	142	303	19,5	26,5
	4	L-T	77250	200	345	17,1	27,0
	10	L-T	72250	200	316	18,7	23,8
	20	T-L	---	173	328	22,0	27,1
	20	L-T	---	185	326	17,3	22,1
6082	4	T-L	77250	316	340	11,7	23,2
	4	L-T	73000	316	340	10,1	22,4
	8	T-L	69750	203	287	17,6	27,7
	8	L-T	69750	207	294	17,4	23,6
	17	T-L	---	245	332	17,6	25,9
7020	4	T-L	74500	321	372	12,6	30,0
	4	L-T	75000	322	374	15,9	26,5
	8	L-T	70000	356	402	23,0	18,4
	20	L-T	---	370	417	12,6	20,7

Fig.2: Material properties of tested alloys

After assembly of the welded plates test specimens were cut out and a starter notch was introduced into the specimen by milling for fracture testing. Specimens for base material, heat-affected-zone (HAZ) and the weld material were for the different thicknesses as above, Fig.4. Finally specimens were alloed to age naturally for several months. Especially for the heat-treatable alloy 7020 the selfhardening procedure was thus activated.

Alloy	t	Wire	ϕ	No. of Passes	Proced.	Current	Gas
	mm		mm			A	l/min
5083	4	5183	1,6	1	MIG-A	230	22
	10	5183	1,6	2	MIG-A	280-310	22
	20	5183	1,6	5	MIG-A	280-320	22
6082	4	5183	1,6	2	MIG-A	200	22
	8	5183	1,6	3	MIG-A	260-280	22
	17	5183	1,6	4	MIG-A	240-300	22
7020	4	5183	1,6	1	MIG-A	230	22
	8	5183	1,6	3	MIG-A	250-260	22
	20	5183	1,6	5	MIG-A	270-320	24

Fig.3: Welding parameters of tested aluminium plates

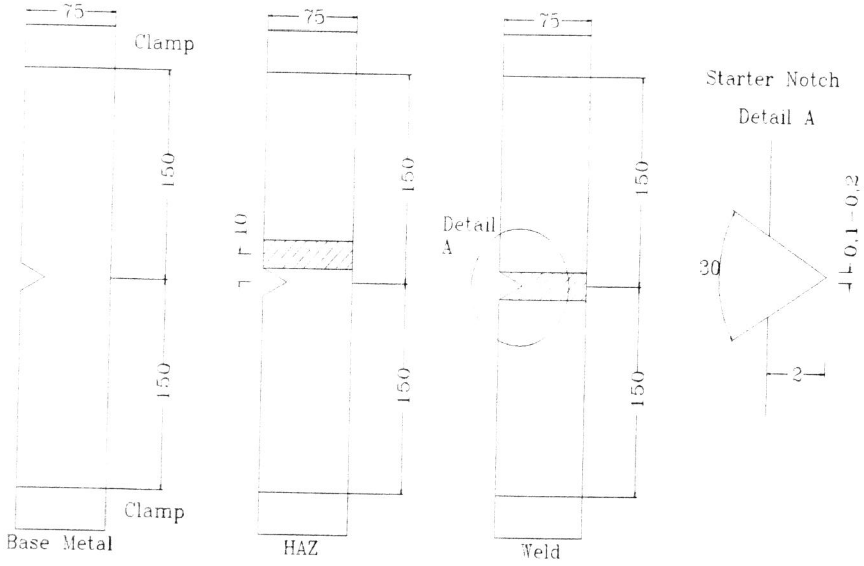

Fig.4: Test specimens for crack propagation measurements
All sizes in mm

TEST CONDITIONS

All specimens were tested with a computer-controlled servo-hydraulic pulser and all data were measured by a second computer with a fast analog/digital device performing 16000 measurements per second [5].

In the first phase a fatigue induced crack was introduced in the starter notch by cycling on a relatively high stress range. After that the stress range was reduced approx. 5 to 6 times in 15% steps reaching a region of about K≈80-100 $N/mm^{3/2}$ where a constant load spectrum was applied up to the end of the test, i.e. final rapture. During two consequtive load cycles the load F, the deformation v of the specimen and the local deformation at the crack tip through the crack opening displacement COD were documemnted with approx. 400 single measurements. The crack length was be calculated by the compliance method.

The tests were performed at three different stress ratios $R=\sigma_{min}/\sigma_{max}$ with values of R=-1/0/+0.5. An outline of the performed tests is given in Fig.5.

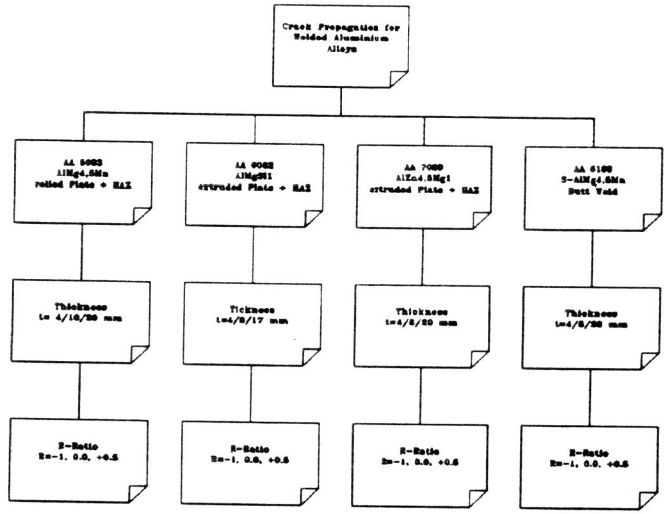

Fig.5 Outline of investigated parameters

TEST RESULTS

Some 250 million single data points were recorded for the whole investigation programme. Effects of the two main parameters, plate thickness and R-ratio, were examined in the initial crack propagation vs. stress intensity diagrams. A harmonization of results was demonstrated through the subsequent plotting of results in crack propagation vs. effective stress intensity diagrammes. Information on measurements, test results, crack closure measurements and comparative analysis of results are given in full detail in [5, 6]. The following diagrammes demonstrate some of the principal findings of this research programme.

No significant difference could be observed due to plate thickness for any of the investigated alloys. As an example the results of such an analysis are given for the 7020 alloy both vs. ΔK and ΔK_{eff}, Fig.6.

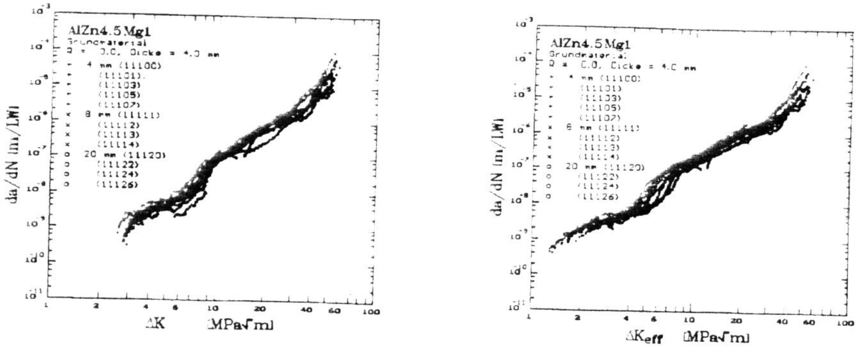

Fig.6: 7020 Crack Propagation for plate thickness t=4/8/20mm

On the other hand an R-ratio effect was definitely present. As was expected crack propagation values increased towards positive R values. This effect was nevertheless wiped out when test data was plotted against effective stress intensity factors, accounting thus for crack closure effects. A characteristic relationship is shown in Fig.7 for the alloy 7020 in t=10mm base material. Similar diagrammes have been observed for the other alloys, plate thicknesses, heat affected and weld zone.

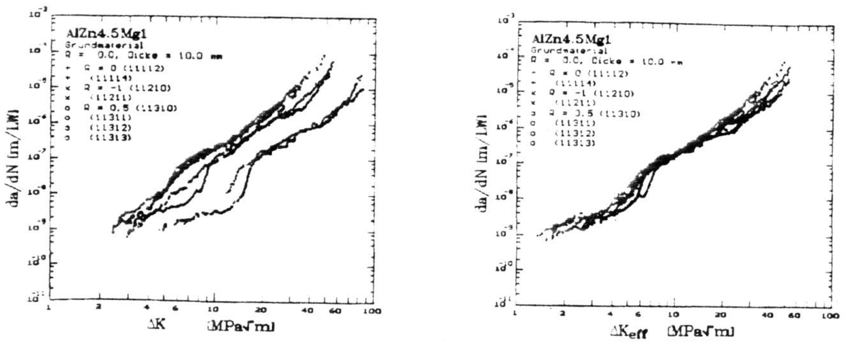

Fig.7: 7020 Crack propagation for R-ratio R=-1/0/+0.5

Representative crack propagation values for the alloys 6082 and 5083 in the heat affected zone are reproduced in Fig.8 for plate thickness t=8 and t=10mm respectively. Fig.9 gives the results of measurements in the weld zone (5183 wire) of 5083 butt joints.

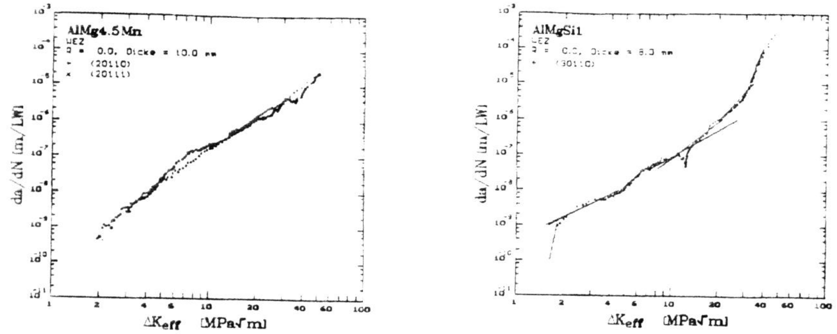

Fig.8: Crack propagation for 5083 and 6082 HAZ

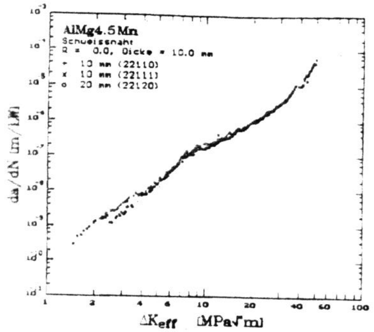

Fig.9: Crack propagation for weld material 5183

CONCLUSIONS

The crack propagation data on aluminium weldments reported constitutes a comprehensive data base for respective assessments of structural components. Different material and weldment zones, R-ratios and plate thicknesses covered allow application to a wide range of structural details. Of significant importance for actual utilization of this information will be the integration of the data into the Aluminium Data Bank as well as the statistical evaluation of the experimental measurements, so that suitable design lines accompanied by respective reliability statements can be drafted.

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