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EFFECT OF NOTCH SHARPNESS AND COLD EXPANSION ON THE FATIGUE CRACK ARREST

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ABSTRACT

A fatigue crack can be stopped by a decrease of the notch sharpness and by residual compressive stresses at the crack tip [1]. The decrease of the notch sharpness is generated by a drilling at the crack tip and the residual compressive stresses by a cold expansion. This work is about two aluminium alloys which are used in land transport components. Three drilling radius and five expansion rate were performed at the crack tip. The required number of cycles to obtain a new crack initiation, the crack propagation rate and the crack tip opening displacement are studied and analysed from the different cases.

The necessary number of cycles to obtain a new crack initiation is called Time Life. The curves time life versus the applied stress are similar to the Wöhler curve and the same use can be done. The residual compressive stresses and the plastic zone size are determined from a numerical calculation code .

Without any cold expansion the fatigue life is controlled by the local stress concentration factor. In this case the fatigue life can be explained from a power law of the hole radius[2].

The crack propagation rate is minimum at the crack initiation and is depending on the hole radius too. After the new crack initiation we find again the crack propagation law of the initial material.

By practising a cold expansion, the time life is strongly improved and the minimum crack propagation rate is lower [3,4,5,6]. We can observe a limit in the time life improving exceptif the crack expansion degree become too high the time life strongly decreases. The cold expansion brings residual stresses, plastic deformations and the local microstructure is modified. The fatigue life depends on the cold expansion degree but it is difficult to identify the separated effect of residual stresses, of the plastic deformation and of the microstructure.

KEYWORDS

Notch sharpness, cold expansion, time life, residual stresses, crack propagation

INTRODUCTION

The propagation of fatigue crack often leads to fracture of components. Therefore it is possible to extend the time life by decreasing the notch sharpness and introducing residual compressive stresses [6]. An usual technique to decrease the notch sharpness is the drilling at the crack tip and to induce residual stresses is the cold expansion. The expansion degree is defined by the relation DCE % = $100*(3- _{p})/$ where $_{p}$ is the drilling radius.

By this way we can stop the crack propagation for a more or less time which is called "Time life". After a new crack initiation the crack propagation rate is lower than before drilling and that contribute to the security working.

In the present study, the hole drilling and cold expansion hole are investigated. Three radius value and five expansion degrees have been used. The hole radius successively were 1.0; 2.5 and 3.0 mm. In this case the time life is controlled by the local radius and the local stress concentration factor. The cold expansion has been performed in order to get a final radius of 3 mm, the initial radius were slightly smaller so the expansion degrees varies from 0% to 9.0%. As we'll see later there is a limit on top a certain level the cold expansion is damaging.

EXPERIMENTAL PROCEDURE

We used two aluminium alloys 60XX. that means its contents Magnesium and Silicium. These alloys are used for drawing at cold and mid temperature - working.
The composition and the main mechanical properties are respectively given in the table 1 . The true stress versus true strain shows a low stress hardening.

Alloy	Mg	Si	Fe	Cu	Mn	Cr	Zn	Ti		Re	Rm	E	A%	Hv_{50}
60XX1	0.45	0.5	0.26	0.2	0.23	0.16	0.09	0.04		245	273	68	12	9010
60XX2	0.6	0.7	0.24	0.06	0.9	0.02	0.06	0.02		280	327	68	12	9510

TABLE 1 CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES

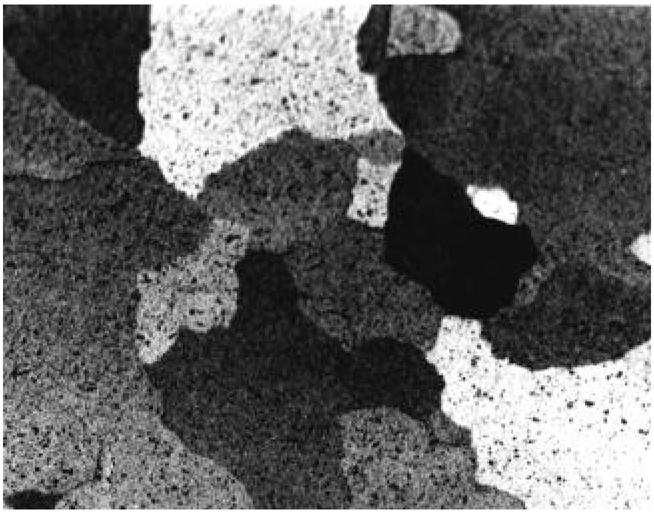


Photo 1 Microstructure Alloy 60XX1

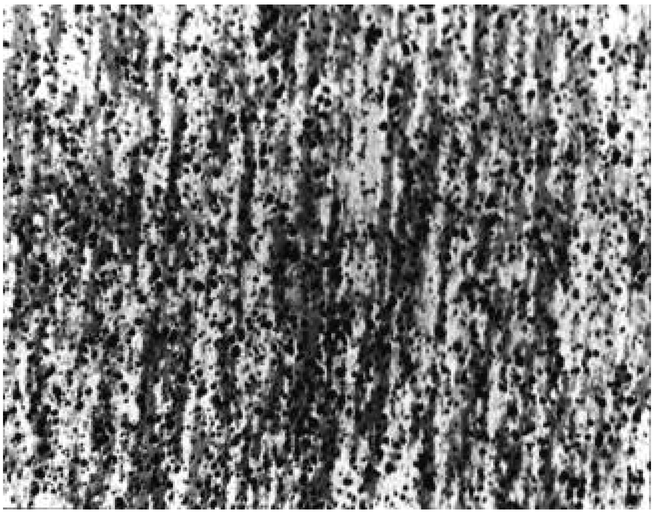


Photo 2 Microstructure Alloy 60XX2

The first alloy presents a constituted microstructure of coarse grains without any precipitates (photo 1) the microstructure of the second alloys presents fine grains where we can detect very small precipitates (photo 2).

The specimens were cut from aluminium alloys plates of 5mm thick, with the axe parallel to the rolling direction of the plates. A slit of 1mm in width and 15 mm in length was machined at one lateral side of specimen. A pre crack from the slit tip was introduced by cyclic loading and the total length of the slit and the pre-crack was $(a_0 +) = 27.5$ mm. A hole was machined at the pre-crack tip. The hole was first drilled conventionally and then carefully enlarged by a boring bar to a desired radius [2].

The cold working expansion process was realised by forcing a hard steel ball of 6mm in a diameter slightly smaller pre-drilled hole. A burnished surface of the expanded hole was obtained and the surface structure was refined by plastic deformation leaving at the hole surface.

The geometry and the dimensions of specimens are given on the figure 1

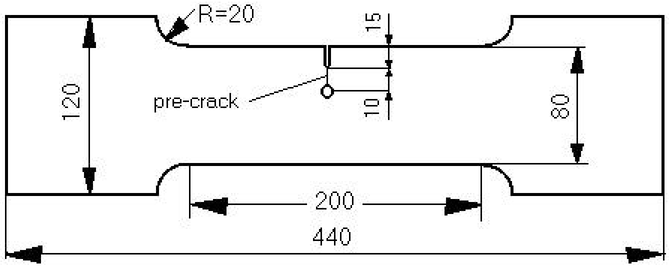


FIGURE 1: SPECIMEN SHAPE

The specimens were subjected to cyclic loading at room temperature with a sinusoidal waveform of a frequency of 30 Hz. For all tests the stress ratio (S_{min}/S_{max}) is the same and taken at the value 0.57. In this condition then crack is always opened.

EXPERIMENTAL RESULTS

From the curves crack length versus number of cycles fig(2) we can determine the time life and the minimal crack propagation rate versus hole radius and versus cold expansion degrees table 2. For each case the time life versus stress amplitude can be put in the form of power law in the same way that the well known Wöhler curves.

The fatigue limit corresponding to a time life of $2*10^6$ cycles can be expressed from the hole radius by a law N = N_0*. where N_0 corresponds with = 1.

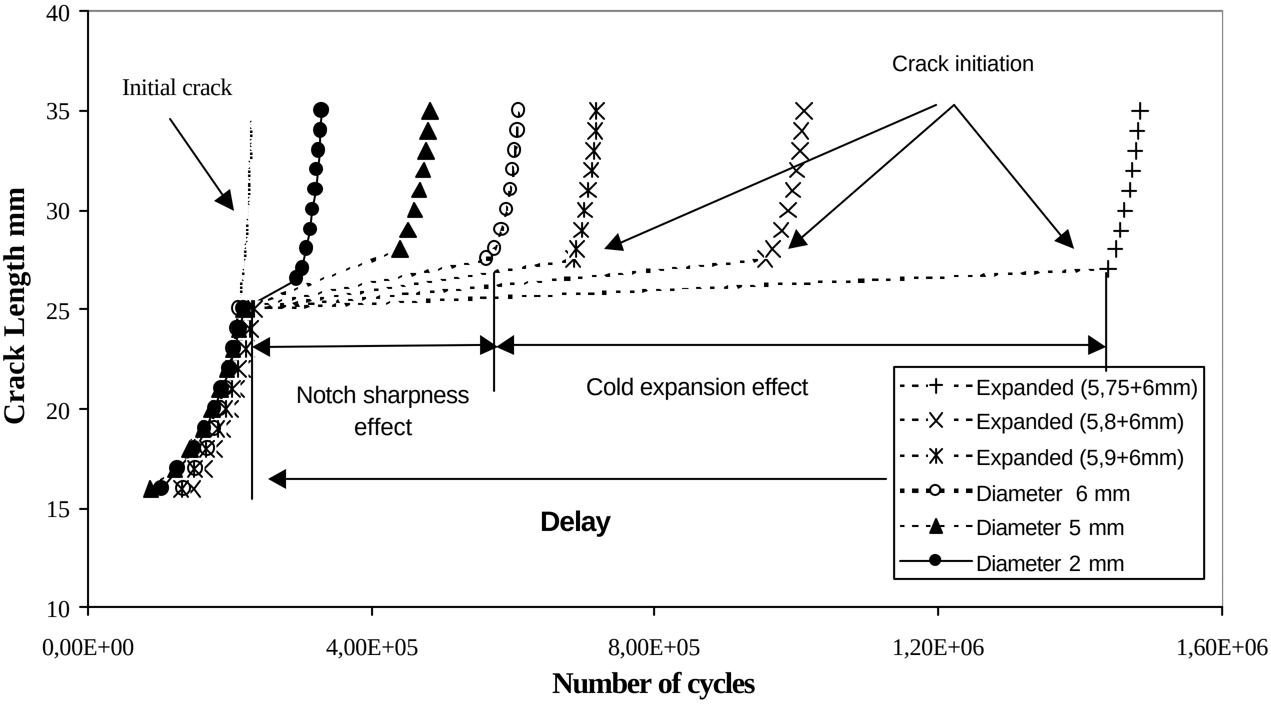


FIGURE 2: CRACK LENGTH VERSUS NUMBER OF CYCLES

The figure 2 shows clearly the crack arrest and the great time life gain we can get by modifying the notch sharpness and the cold expansion.

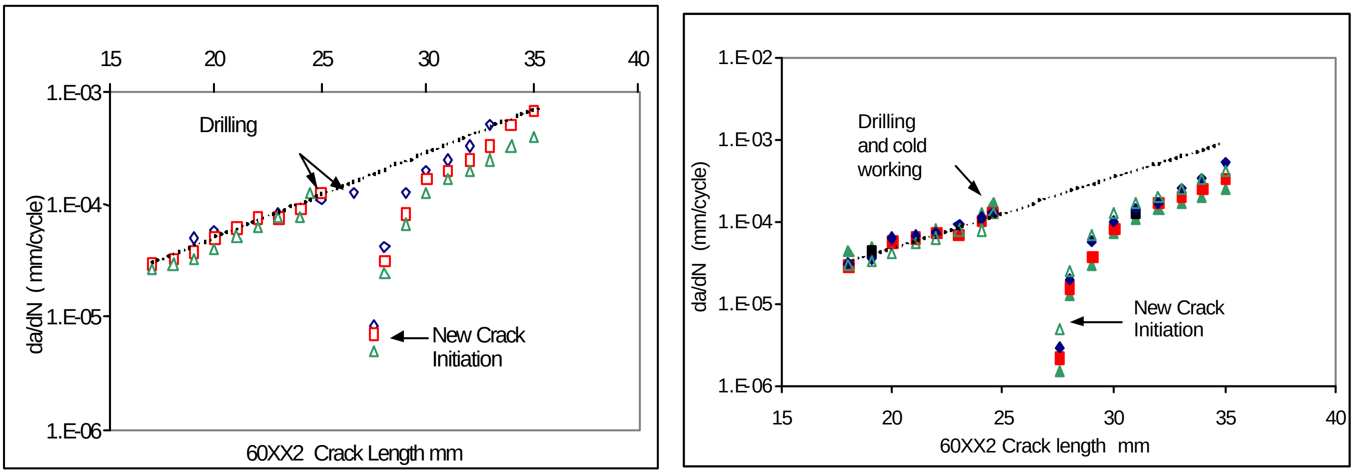


FIGURE 3: CRACK PROPAGATION RATE VERSUS CRACK LENGTH NOTCH SHARPNESS -COLD EXPANSION EFFECT

The figure 3 shows the evolution of crack propagation rate and bring out the notch sharpness effect (hole radius) and the cold expansion effect. A increase of the hole radius and of the cold expansion degree lead to a decrease of the crack propagation rate . We have to notice after cold expansion the crack propagation rate don't go back initial value, that means the parameters of the PARIS law have changed.

	Radius in mm					Radius 3 mm cold working Expansion degree %					
	1 .0	2.5	3.0			0	1.7	3.4	4.3	7.1	9.0
Time Life in kilocycles											
60XX1	75	220	340			340	450	720	1208	211	95
60XX2	119	335	611			611	1040	1420	2000	321	130
Minimum of crack Propagation Rate 10 $^{-6}$mm/cycle											
60XX1	13.6	11.5	8.80			8.80	6.65	4.20	2.50	14.21	31.60
60XX2	8.5	7.1	4.95			4.95	2.80	2.25	1.50	9.34	30.70

TABLE 2: TIME LIFE IN KCYCLES - CRACK PROPAGATION RATE SHARPNESS AND COLD EXPANSION DEGREE (NOMINAL STRESS 28.5 MPA)

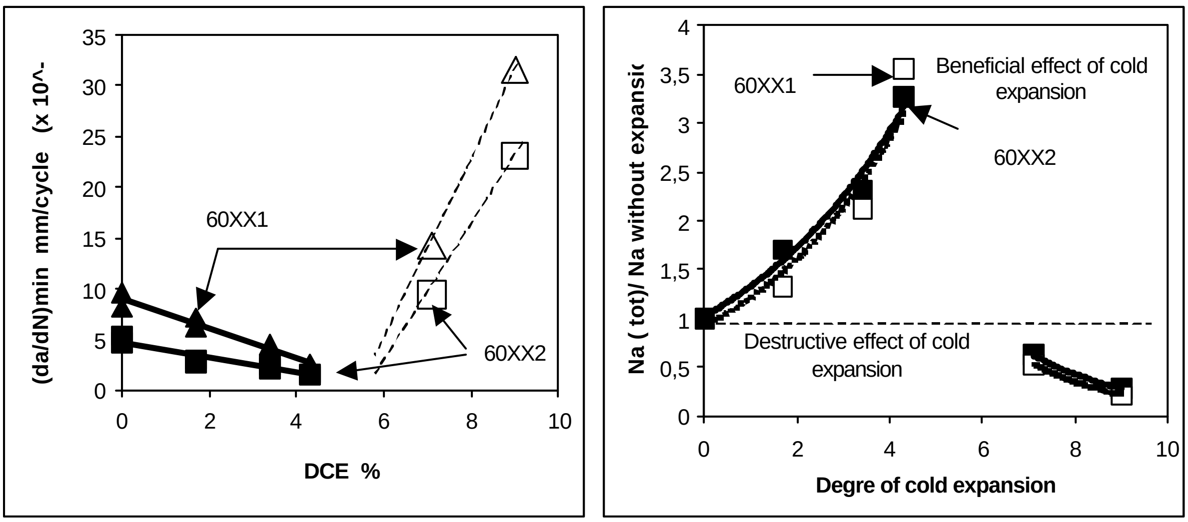


FIGURE 4: COLD EXPANSION EFFECT BRING OUT OF DAMAGING AFTER A TOO HIGH C.E.D

The figure 4 shows that over a value of the cold expansion degree, we clearly notice a decrease of the time life and an increase of the crack propagation rate. In these cases the expansion becomes disadvantageous compared with a single drilling. In our case for both alloys we find the behaviour inversion for a expansion of 5.5%.
The residual stresses and the plastic zone size were calculated from a numerical code (F.E.M IDEAS code in 3D). The results are given on the table 3.

	Residual stresses MPa			Plastic Zone Size mm		
	C.E.D 1.7%	C.E.D 3.4%	C.E.D4.3 %	C.E.D 1.7%	C.E.D 3.4%	C.E.D4.3 %
60XX1	295	317	335	4.38	5.68	6.39
60XX2	310	340	360	3.80	5.02	5.05

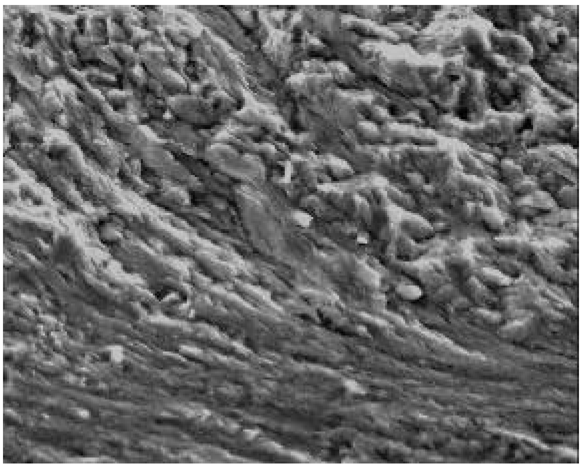
TABLE 3: RESIDUAL STRESSES AND PLASTIC ZONE SIZE VERSUS COLD EXPANSION DEGREE

The residual stresses act like a vice so the crack tip opening displacement is strongly dependents on the cold expansion degree. The results are given in three cases (table 4). We can notice a quasi stability in the absence of any expansion. In the presence of an expansion, the crack opening decreases in the first cycles of loading the a stability. Consequently, we can have a stresses redistribution during the first cycles.

Crack tip opening displacement mm			
	1 cycle	50000	10^5
Fatigue crack	0.624	-	-
Radius 3 mm	0.318	0.318	0.290
Expansion 4.3%	0.211	0.162	0.165

TABLE 4 CRACK TIP OPENING DISPLACEMENT

The Scanning Electron Microscopy shows the plastic deformation at the crack tip and into the zone near the crack tip we don't notice any micro crack the residual compressive stresses and the plastic deformation resulting from cold expansion closed these ones. On the other hand, far from the crack tip into the initial structure we notice a lot of micro-crack.


Near the crack Tip

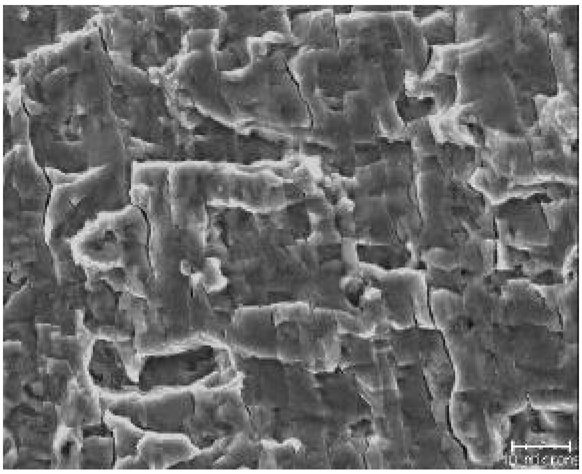

Far from the crack tip

PHOTO 3: SCANNING ELECTRON MICROSCOPY OF FRACTURE

CONCLUSION

The time life and the crack propagation rate minimum can be explained from a power law of the hole radius. The cold expansion bring a advantageous effect until a limit value, over this value the expansion is damaging. The advantageous effect can be explained in the same way that the hole radius effect. The time life versus the stress amplitude leads to similar curves that Wöhler curves and they can be used in the same way. The residual compressive stresses and the plastic zone size was calculated from three dimensions F.E.M. Alone Theses parameters can't explain the material behaviour . The local microstructure modifications must have a great part in the new crack initiation. The crack tip opening displacement can be used as a picture of the hole radius, of the cold expansion and of the residual stresses distribution.

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