AN EFFECT OF SHOT PEENING ON GROWTH AND RETARDATION OF PHYSICALLY SHORT FATIGUE CRACKS IN AN AIRCRAFT Al-ALLOY

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Resume

Results of an investigation of effect of shot peening on development of physically short fatigue crack in an aircraft V-95 Al-alloy, which is of a similar type as 7075 alloy, are described and discussed in the paper. The first part deals with adaptation and verification of direct current potential drop method for detection and measurement of short crack initiation and growth. The specific material and quite large dimensions of flat specimens with side necking of a low stress concentration factor had to be considered when position of electrodes was specified and the measurement method verified. The specimen type and dimensions were proposed taking account of the investigation of shot peening effects. Physically short fatigue cracks of the length from 0.2 mm to more than 3 mm, most of them between 0.8 – 1.5 mm, were prepared under high cycle fatigue loading of a constant nominal stress amplitude ±160 MPa. Specimens with existing short fatigue cracks were shot peened using two different groups of parameters. Development of crack growth after shot peening was measured and compared with crack growth in specimens without shot peening. Retardation of crack growth was significant particularly with cracks shorter than 2 mm. For the specific stress amplitude, evaluated results enable to estimate threshold length of defects, which after the application of shot peening will be reliably arrested.

Keywords: *Shot peening, fatigue crack growth, fatigue life, aircraft Al-alloy.*

1. Introduction

Shot peening is surface treatment applied to various metallic materials either separately or after previous surface treatments like plating, hard anodising etc., in order to locally improve the performance of mechanical components under fatigue loads [1,2]. These treatments create a compressive residual stress and material local hardening that usually increase the operating life of the component. In order to perform an effective and reliable design, it is not adequate to consider only the in-service stress of the component. Unexpected cracks could occur due to the fact that tensile residual stresses added to the in service stress decrease the component life; at the same time a strong improvement can be achieved, if compressive residual stresses are induced in the components.

The final effect of shot peening on fatigue resistance depends on numerous parameters and material which the technology is applied to. If the technology parameters are not optimised for a specific material and for its basic structural and mechanical properties, shot peening may not be beneficial, fatigue resistance can even be deteriorated [3,4]. Recent advanced approaches are based on the hypothesis that the compressive residual stresses are able to slow down/stop cracks propagation instead to prevent their formation, and therefore there are based on main concepts of fracture mechanics.

In specific cases of materials, this hypothesis requires the development of tests aimed at investigating the influence of shot peening on propagation of short fatigue cracks. In the next step, the results have to be compared with results of traditional fatigue tests with the aim to assess if and in which situations fracture mechanics can be used to predict the fatigue strength of shot peened components.

The mentioned approach of evaluation of shot peening favourable effects is connected with high demands on sophisticated experimental methods, particularly preparation of physically short fatigue cracks in specimens of reasonable dimensions suitable for shot peening applications and exact measurement

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of actual crack length including not only surface path but also an estimation of crack profile inside the specimen. Length of short cracks is usually measured optically (e.g. [5]), which however does not enable to assess the subsurface length at all. Complex crack growth measurement including subsurface profile, which is an essential condition of application of fracture mechanics approaches, is not an easy task, particularly if specimens are of quite big dimensions.

In the first part of this paper, problems and possibilities of measurement of short crack growth are analysed and discussed. The second part of the paper then contains results of the experimental programme aimed at an evaluation of shot peening effects on retardation of short fatigue cracks applied to specimens of Al-alloy containing short fatigue cracks preliminarily prepared by fatigue loading.

2. Experimental material

Before describing experimental methodology, it is necessary to mention experimental material, because the methodology had to be adapted just to the specific material properties. The work was addressed to potential use in aircraft industry with the aim to investigate conditions of retardation of small cracks or crack-like defects using shot peening. Therefore, Al-alloy V-95 was selected as the experimental material. The V-95 material is a Russian Al-alloy of Al-Zn-Mg type and due to its high mechanical properties and fatigue resistance, it has been widely used for construction of aircraft structures, such as wings and fuselages, already for many years [6]. According to Russian GOST standard, the typical chemical contents of Zn is 5-7 weight %, Mg 2-3 %, Cu approximately 1.5 % and Mn 0.35-0.6 %, whereas chemical composition affects quite strongly the material hardenability [7]. A similar US type of the material is represented by a 7075 Al-alloy with just slightly lower content of Zn and Cu. Typical values of basic mechanical properties of this material at heat-treated conditions are: strength up to 550 MPa and yield stress up to 480 MPa.

The V-95 alloy was available in the form of sheets of thickness 2.1 mm in Aeronautical Research and Test Institute in Prague, where specimens also were manufactured.

3. Method of measurement and evaluation of short crack length

Three essential demands on the method of measurement short crack length consisted in (i) possibility to detect short crack initiation in terms of detecting crack of the length at least 0.2 – 0.3 mm in the quite large specimen to be used for the investigation of shot peening effects and (ii) ability to detect cracks during high cycle fatigue loading without necessity to remove the specimen from the fatigue machine and (iii) possibility to assess subsurface growth and shape at least in terms of fracture surface area inside the specimen. After considering the requirements, it was decided to use a modified direct current potential drop (DCPD) method.

As already mentioned, the specimen was of quite big dimensions given by material aviability, namely material sheets of the thickness 2.1 mm, and technological reasons of the shot peening application. Flat specimens of the V95 Al-alloy sheets of the thickness 2.1 mm, total length 200 mm and basic width at gripping area 48 mm were manufactured. To localize the area of crack initiation and to enable subsequent shot peening of specimen edges, shallow necking were made from both the specimen sides. The necking radius was 28 mm, the minimum width at the specimen center was 24 mm.

Using previous theoretical knowledge and wide experience with the use of DCPD method in various cases [8,9], sensitivity analysis of analytical calibration curves on the position of potential electrodes near the crack mouth was carried out for the specific specimen dimensions as the first step. The most important results are shown in the Figs. 1-2.

It follows from Figs. 1 and 2 that the distance of potential electrodes from the crack initiation site or crack mouth, respectively, should be as low as possible to ensure a sufficient sensitivity of the method. Taking account of the typical scatter of DCPD measurement with the equipment used, corresponding to potential ratio changes about ± 0.001, the method is sufficiently sensitive, if the distance of potential electrodes is less than 5 mm, whereas the distance of 10 mm can still be considered as acceptable, being able to detect cracks of the length between 0.2 and 0.3 mm.

Another experimental problem, however, was a connection of measurement potential electrodes very close to the central part of the specimen. As the central necking was quite shallow with a negligible stress concentration factor, stresses values in the specimen center, where cracks were expected to initiate, and distance between 5-10 mm from the specimen center corresponding to the optimum position of electrodes, were almost equal. Therefore, spot welding as a usual connecting method could not be used due to creation of microstructural notch.

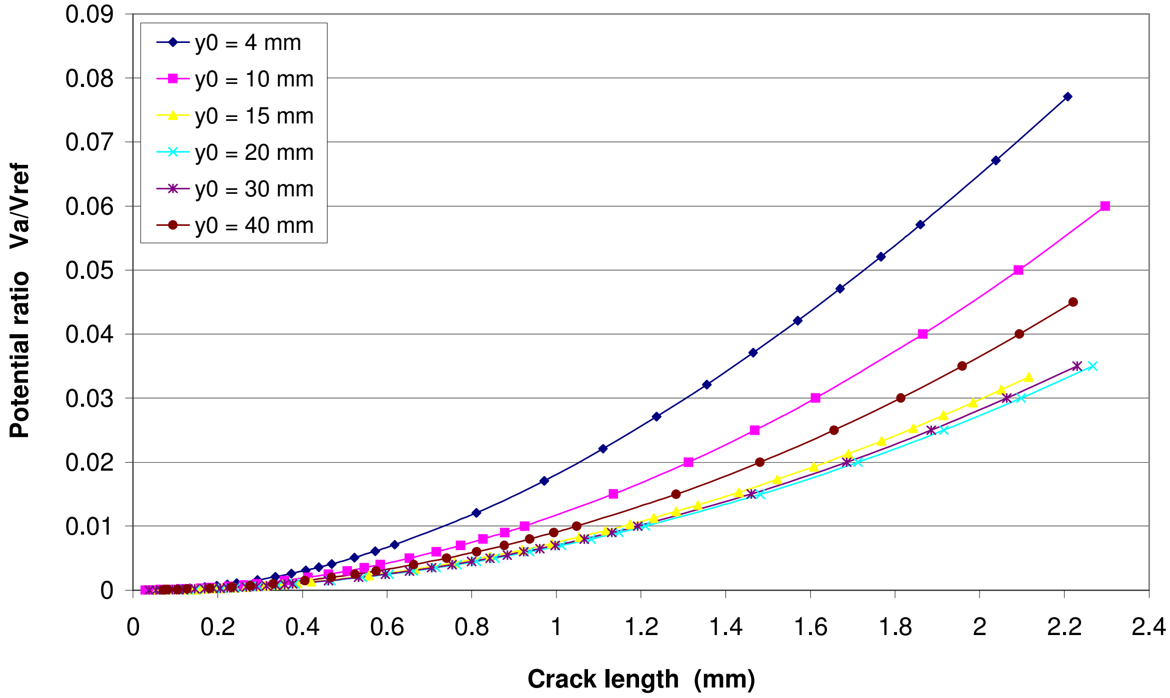

Fig. 1. Analysis of DCPD sensitivity on distance of potential electrodes from crack mouth

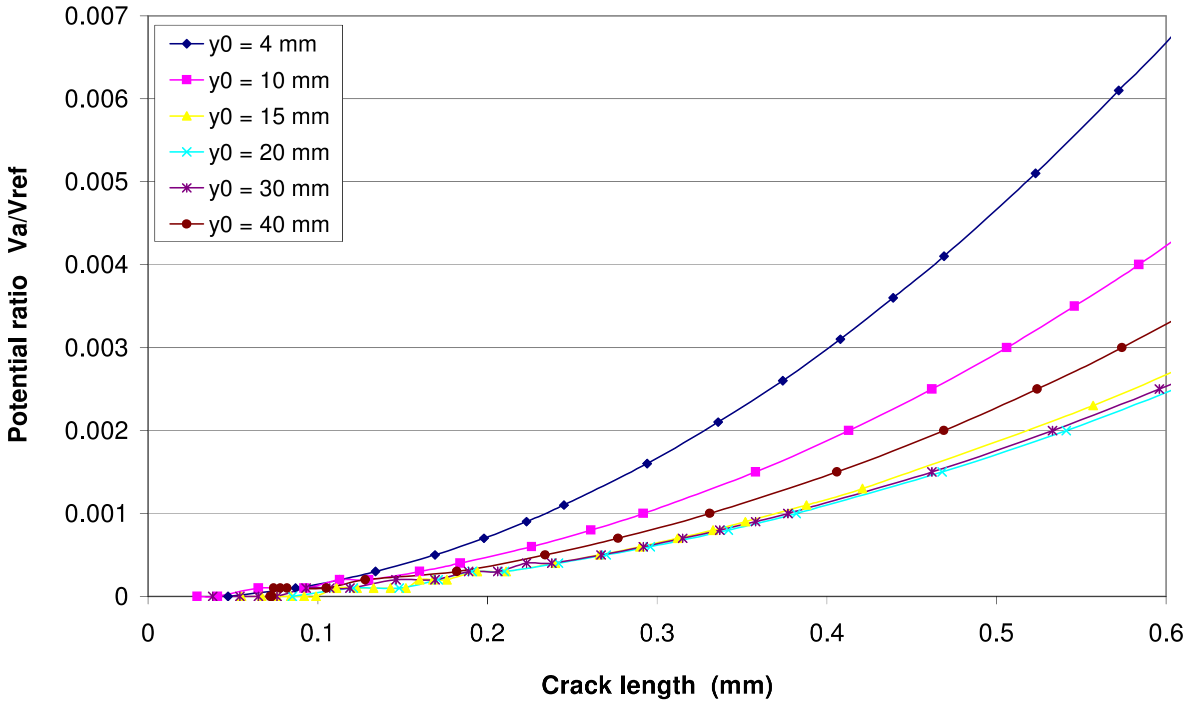

Fig. 2. Detailed DCPD sensitivity analysis on distance of electrodes for very short crack lengths

As an alternative, narrow self-adhesive Cu strips were attached to the specimen sides as potential electrodes – Fig. 3 and possibilities of this method were verified.

The results were promising for static loading. However, during high cycle fatigue loading, the connection was not sufficiently durable and reliable (Fig. 4). Particularly in case of “lower” electrodes, the connection was poor from the point of view of electric conductivity caused just by very small weight of thin Cu strips. The same case occurred if special conductive vaseline was used as connecting medium.

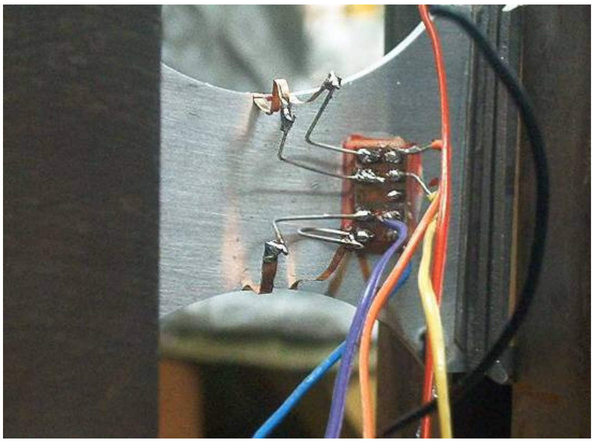

Fig. 3. Specimen with narrow Cu self-adhesive strips used as potential electrodes

The next attempt to connect potential electrodes was soldering. Thin Cu wires were attached using a special soldering metal suitable for Al alloys. However, as the minimum melting temperature necessary for a reliable connection exceeded 450 °C, fatigue resistance of the heat treated V-95 alloy was locally reduced resulting in crack initiation under the electrodes instead of the specimen center – Fig. 5. The local changes of the resistance to fatigue crack initiation were likely caused by microstructural and hardness changes due to the heating of the edge to the soldering temperature, though it took effect just for a short time.

Due to the problems of connecting electrodes close to the specimen center, which were specific for the investigated material and would not occur with steels as an example, it was eventually decided to increase the distance of electrodes to more than 30 mm, where nominal stress value was sufficiently lower. However, to achieve the adequate measurement precision and eliminate the undesirable scatter, DCPD measurement had to be performed under static loading, i.e. fatigue loading had to be always interrupted. In addition, the measurement had to be repeated at least 20-times and average value of the potentials calculated. This procedure was very time consuming, but unavoidable for achieving the investigation goals.

The photographs in Figs. 6 and 7 document the rightness of the application of the DCPD measurement method. Fig. 4 shows a typical shape of the short crack front in the specimen, which was broken in order to verify the accuracy of the measurement. Cracks were always initiated at the specimen sides, if initiation under the electrode was excluded. If crack was initiated near the edge like in Fig. 6, which was a frequent case, then the shape was quarter-circular. Optical measurement would then provide results with quite a big error. In addition,

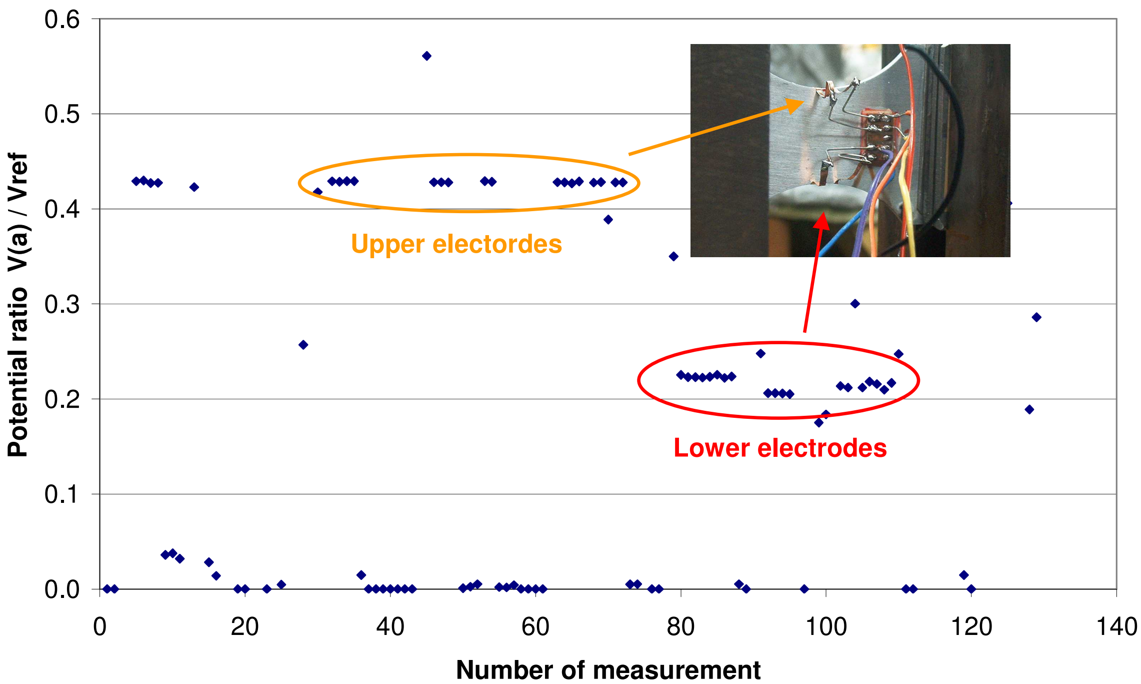

Fig. 4. Verification of use of self-adhesive Cu strips as potential measurement electrodes

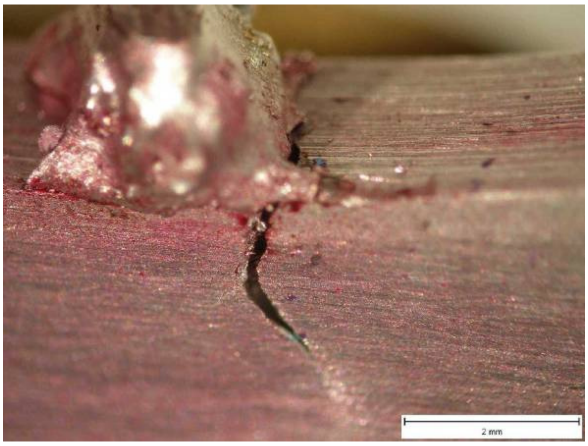

Fig. 5. Example of crack initiation under soldered potential electrode

there was another difficulty. Due to the material plasticity and creating a special surface layer, very short crack of the length lower than 0.2 – 0.3 mm usually could not be optically observed at all. This is shown in Fig. 5, where the crack of the surface length 1.05 mm is not visible in the are close to the specimen edge.

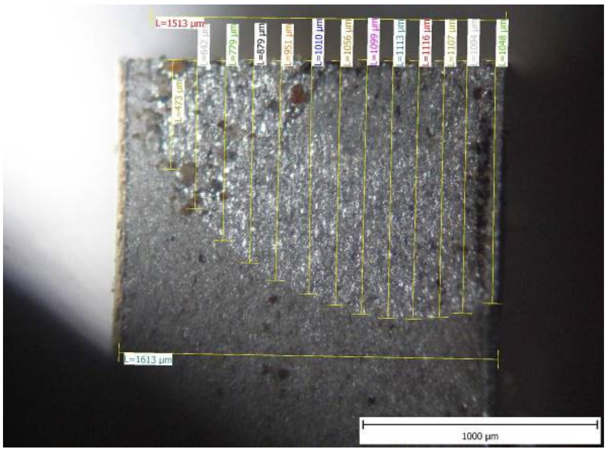

Fig. 6. Typical quarter-circular shape of short crack front initiated near the edge (upper right corner)

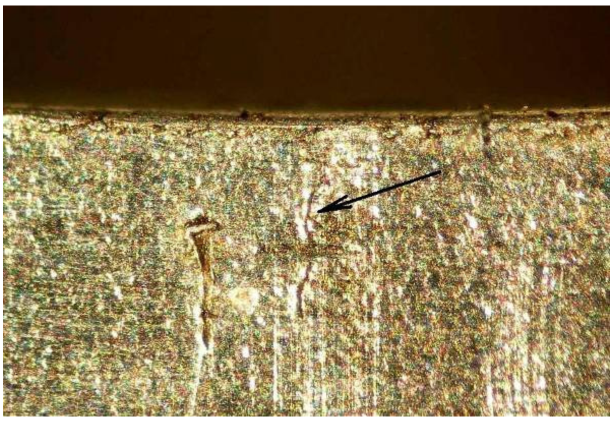

Fig. 7. Crack of surface length 1.05 mm, not visible in the area of specimen side – initiation site

3. Effect of shot peening – results and discussion

Using the adapted and verified methodology of short crack measurement by DCPD method, fatigue cracks of different length between 0.35 mm and 3.6 mm were prepared in 17 specimens, whereas the length of most of the cracks was between 0.87 mm and 1.49 mm (9 specimens). The nominal stress amplitude was constant, ±160 MPa, and common for all the specimens. Artificial microscopical notches of dimensions less then 0.05 mm were made on the specimen edges to accelerate the microscopical crack initiation period. After pre-cracking, the specimens were divided into two groups, each of them containing a similar spectrum of cracks lengths so that the groups could be compared to each other. Shot peening of two different parameters was applied at Technometra Radotín a. s. to the first and second group, respectively. Parameters of the shot peening were: Balottini sizes 0.43 – 0.7 mm and 0.21 – 0.32 mm for the first group and second group, respectively, Almen intensity A = 0.25 and A = 0.14 for the first and second group respectively. Shot peening angle was 60^{o} and coverage 200% for both groups. Both edges in the central area of specimens were shot peened from both sides to the distance of 4 – 5 mm from the edge. Shot peening area can be seen in Fig. 8.

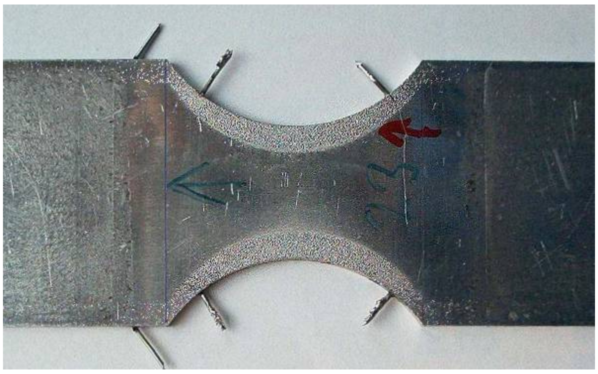

Fig. 8. Specimen after application of shot peening with potential and reference electrodes

Survey of results of fatigue life after application of shot peening in comparison with untreated specimens is shown in Fig. 9. As regards the fatigue life of specimens without shot peening, tested to failure at the same stress amplitude, the total life was much longer, not only between 5000 and 8000 cycles as shown in Fig. 9. The experimental points of these three specimens namely correspond just to the crack growth stage starting with the length 0.2 mm, which could be reliably detected and measured by the DCPD method.

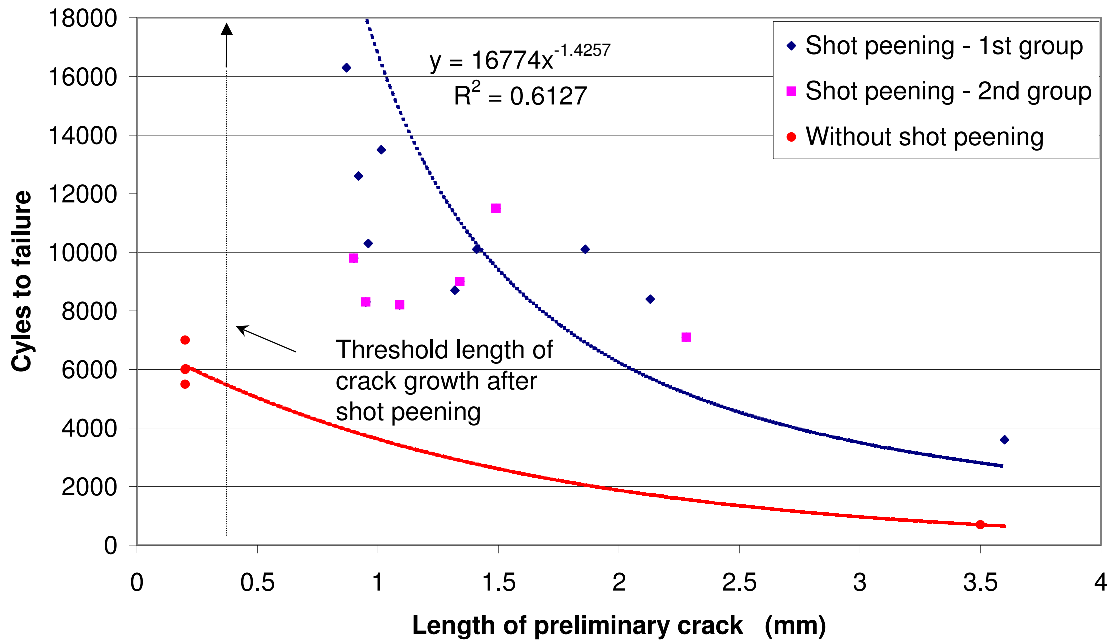

Fig. 9. Fatigue life after application of shot peening in comparison with untreated specimens

It follows from Fig. 9 that the retardation effect resulted from shot peening was quite significant. In the region of crack length around 1 mm, the estimated increase of fatigue life is at least between 2- and 3-times, the effect being stronger for the first group of shot peening parameters. However, even for cracks longer than 2 mm, some retardation effect is evident.

Results in Fig. 9 enable to estimate the threshold length of the total crack arrest. The estimation was made on the basis of extrapolating the regression line for the shot peened specimen groups, the estimated value being approximately 0.35 mm. The threshold value was indirectly verified, when one of the specimens with the preliminary crack of the length just 0.35 mm, treated with the 1st group of parameters, more effective for short cracks, was tested to failure.

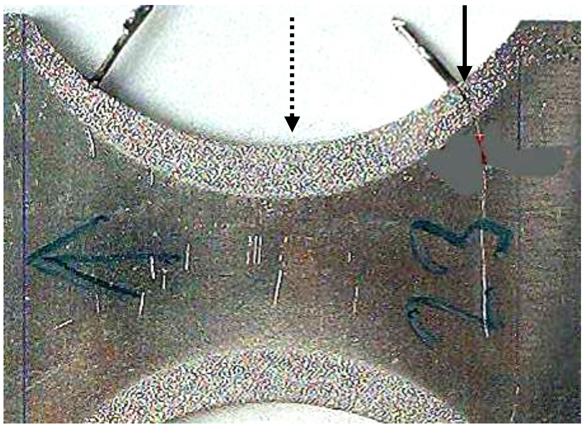

Fig. 10. Crack initiation under electrode (upper right) in shot peened specimen with 0.35 mm preliminary crack

The residual life was high, 235300 cycles. In addition, the magistral crack did not grow from the preliminary short crack (dotted arrow in Fig. 10), but was initiated under the potential electrode in the area remote to the specimen center (solid arrow in Fig. 10), where nominal stress amplitude corresponded just to ± 120 MPa, i.e. to 67 % of the stress in the narrowest part of the specimen.

4. Conclusions

An experimental investigation of an effect of shot peening with two different groups of parameters on further growth of physically short fatigue cracks to failure in an aircraft V-95 Al-alloy was carried out. The significant fundamental part of the work was an adaptation and verification of methodology necessary for detection and measurement of physically short cracks of length exceeding 0.2 mm. The main conclusions can be summarised as follows:

- The direct current potential drop (DCPD) method was successfully adapted and verified as the most suitable one because of possibilities to detect short cracks of the length approximately 0.2 mm and ability to assess average crack length including crack front inside the specimen.
- The specific material and necessary quite large dimensions of the flat specimens with side necking of a low stress concentration factor were considered when position of electrodes was specified and the measurement method verified.

- Spot welding of potential electrodes could not be used for attaching the electrodes due to creation of structural notch and subsequent crack initiation under the electrode. Similar problems occurred even with soldering. Therefore, electrodes had to be placed in the area remote from the specimen center, which reduced the DCPD sensitivity and increased scatter.
- Physically short fatigue cracks of the length from 0.2 mm to more than 3 mm, most of them between 0.8 – 1.5 mm, were prepared under high cycle fatigue loading of the constant stress amplitude ±160 MPa. Development of crack growth after shot peening was measured and compared with crack growth in specimens without shot peening. Retardation of crack growth was significant particularly with cracks shorter than 2 mm. Some minor differences between the two groups of shot peening parameters were ascertained.
- Evaluated results enabled to estimate for the specific stress amplitude threshold length of defects corresponding to the total crack arrest. This estimated crack length was approximately 0.35 mm.

Acknowledgements

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