SHOT PEENING TREATMENT AS A BARRIER TO FATIGUE CRACK PROPAGATION IN PURE SHEAR FOR MEDIUM CARBON STEEL +

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Abstract:

In this study, the effect of shot peening process on the fatigue crack growth of o.4C medium carbon steel has been evaluated by conducting Fatigue tests. Torsion were carried out at stress ratio of (R= -1) and at room temperature.
The following conclusions are obtained

1) **It is observed that the fatigue life increases with shot peening process.**
2) **An equation is proposed to describe the behavior of fatigue crack growth under shot peening process. The equation may be written as:**
   $da/dN=150(\Delta\gamma p)^{3.22}a$ **µm/cycle**
3) **For a given crack growth rate and crack length the plastic shear strain range ($\Delta\gamma_P$) is reduced by shot peening process.**

Keywords: torsion Fatigue test, plastic shear strain , shot peening, medium carbon steel

المستخلص:

في هذه الدراسة، تم تقييم تأثير عملية القذف بالكريات المعدنية مع نمو شق الكلال لفولاذ متوسط الكربون 0.4C بواسطة الفحوصات الالتوائية. فحوصات الالتواء تم إنجازها تحت نسبة أجهاد (R= -1) ودرجة حرارة الغرفة. يمكن وضع الاستنتاجات التالية:

١) لوحظ أن عمر الكلال يزداد مع عملية القذف بالكريات.

٢) تم اقتراح معادلة لوصف تصرف شق الكلال تحت عملية القذف بالكريات.ويمكن كتابة هذه المعادلة التاليه : $da/dN=150(\Delta\gamma p)^{3.22}a$ µm/cycle بالصيغة

٢) لقيم ثابتة من معدل نمو الشق وطوله فأن عملية القذف تؤدي الى نقصان في مدى الانفعال القصي اللدن($\Delta\gamma_P$).

Introduction:

In evaluation of components and structures fatigue has became an integral part of the design process in many industries. Therefore components subjected to

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constant and variable amplitude loading must have an improved research which main objective is the properties of the surface. [1]

Fatigue life of structures is known to highly depend on the surface quality, consequently, a great attention is paid to the specification and the realization of surfaces of machined parts when those must be dimensioned in fatigue. Three parameters are usually proposed to describe surface condition 1) a geometrical parameter: surface roughness. 2) a mechanical parameter: residual stress and 3) a metallurgical parameter: microstructure. [2]

Many test structures and analysis methods have been proposed to measure residual stress. In – plane deflection techniques include pointer structures [3] and bent – beam sensors [4]. Out – of – plane devices include micro rings [5] and passive fixed – fixed beam structures [6]. An electrical pull – in voltage technique has also been demonstrated [7].

One of the known ways to improve fatigue resistance and fatigue life is by using the shot peening processes to induce compressive residual stress in the surface layers, making propagation of fatigue cracks more difficult [8].

The compressive residual stress is obtained due to surface plastic deformation and is responsible for increasing fatigue strength in mechanical components [9].

The objective of this paper is to study the effect of shot peening in medium carbon steel specimens subjected to torsion fatigue evaluating the influence of shot peening treatment.

Experimented Procedures

Material and specimens

The material used for this investigation is 0.4% Carbon (medium carbon steel) which is widely used in several engineering industries, and therefore a carbon steel was chosen for the series of test programs, with a chemical composition given in table(1)[10]

Table (1) chemical composition of 0.4c Medium carbon steel (wt %)

Standard	C	Si	Mn	S	Fe
Ref. [10]	0.39 – 0.41	0.12 – 0.15	1.01 – 1.07	0.002 – 0.007	**Remainder**
Experimental	0.41	0.13	1.06	0.005	**Remainder**

De los Rios et al [10] studied a fully -annealed banded structure (see Fig.1) described in details together with its mechanical properties in reference [10]

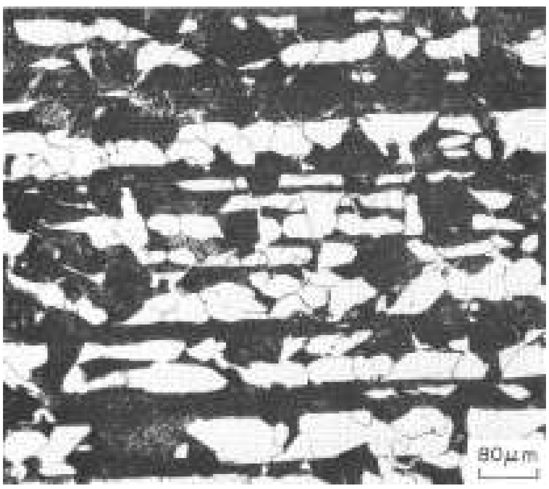

Figure (1) Material Microstructure after [10]

However of importance to this paper are the following data the mean and standard deviation distances between pearilte regions in the longitudinal and transverse directions were 140 ± 93 µm and 50 ± 31μm respectively, whilst the mean diameters of ferrite grains in these directions were 35 ± 26 and 38 ± 23 μm . It follows that cracks propagating in the less fatique resistant ferrite phase had between 3 and 5 grains to transverse in the longitudinal direction before penetrating the more resistant pearlite phase. In the transverse direction frequently only a single ferrite grain provided the initial easy growth path [11] .All these measurements were carried out using the linear intercepts method (L.I.M)

Shallow hour-glass shaped specimen was designed; see Figure 2, which could be used in both tension-compression and cyclic torsion test rigs.

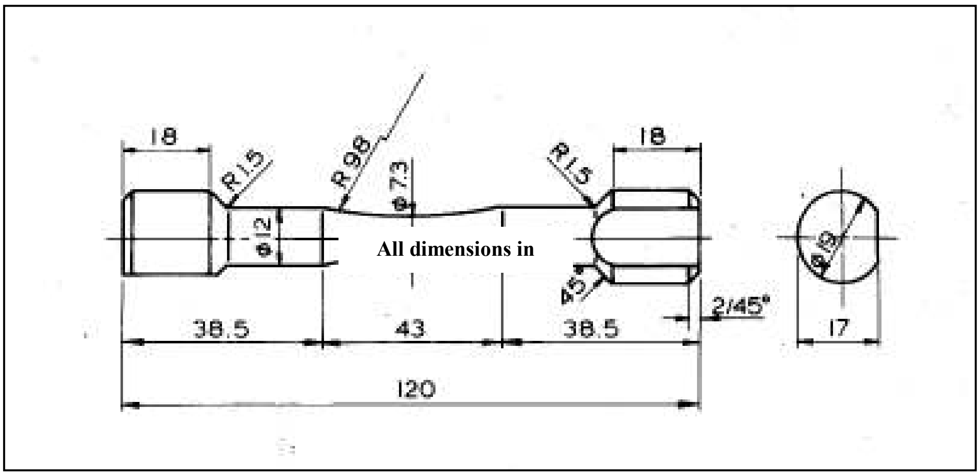

Figure (2) Specimen Geometry

The shallow hour-glass shape facilitated observations of the early growth of cracks which initiated in the vicinity of the minimum cross-section. These cracks being monitored via a replication technique [12]. However this shape of specimen, due to the shallowness of the profile, needs to be calibrated for shear strain determination. For the test report here, the shear stress on the surface is given by [12]

$$\Delta\tau = \frac{\Delta T}{2\pi r}(n+3) \qquad \dots\dots\dots(1)$$

Where $\Delta\tau$ is the shear stress range.

ΔT is the applied torque range

r is the outer radius

The slope n is unity for elastic deformation, but becomes 0.297 for fully plastic deformation, being the cyclic strain hardening exponent. For elastic-plastic deformation the value of n lies between 1.0 and 0.297, and can be measured from the slope of a logarithmic graph of torque versus angular twist [12].
The surface shear strain range at the minimum cross-section ($r=r_o$) was determined from the angle of twist,. $\Delta\theta$, measured over a 43 mm gauge length, to give

$$\Delta\gamma = 0.143\, r_o\, \Delta\theta - 5.771 * 10^{-4}\, \Delta\tau \quad \text{.............. (2)}$$

While the surface plastic shear strain range was given by:

$$\Delta\gamma p = 0.143\, r_o\, \Delta\theta - 1.827 * 10^{-3}\, \Delta\tau \quad \text{................. (3)}$$

In these equations $\Delta\gamma$ is the percentage strain, r_o is in mm, $\Delta\theta$ is in degree and $\Delta\tau$ is in MPa . All specimens were carefully and progressively polished with successively finer emery papers and finely with 6 µm and 1µm diamond paste.

Test rig

The reversal torsion fatigue machine was specially constructed [12] so that both the shear stress amplitude in high cycle fatigue and the mean strain could be independently applied and monitored. For the tests reported here, only constant fatigue tests were carried out at stress ratio (R=-1) at room temperature. All the experiment tests were carried out at the laboratories of the university of Sheffield UK.

Shot peening Process

Specimens were submitted to shot peening with steel shots in accordance to MPE01 – 009 hardness range of 60 – 70 HRC , diameter of 1.0 mm , shot peening intensity used was 0.008 A. The shot peening process was carried out at air [13]

Experimental Results and Analysis

Table (2) shows the constant plastic strain range crack growth measurement for three different levels i-e, high, medium and low subjected to shot peening process.

Table (2) crack growth rate for three different constant plastic shears

$\Delta\gamma p = 0.01$			$\Delta\gamma p = 0.006$			$\gamma p = 0.001$		
a µm	N cycle	da/dN µm/cycle	a µm	N cycle	da/dN µm/cycle	a µm	N cycle	da/dN
150	1740	0.0864	100	22770	$4.4x10^{-3}$	120	49746	$2.4x10^{-3}$
212	13165	0.0161	370	105670	$3.5x10^{-3}$	260	111250	$2.3x10^{-3}$
360	20650	0.0174	610	202152	$3x10^{-3}$	400	310667	$1.28x10^{-3}$
1400	33260	0.0429	1000	356070	$2.8x10^{-3}$	1600	672760	$2.3x10^{-3}$
2500	51620	0.0484	2200	467521	$4.7x10^{-3}$	2800	1,070,321	$2.6x10^{-3}$
3600	77254	0.04659	3600	562172	$6.4x10^{-3}$	3770	1,327,421	$2.84x10^{-3}$
			3800	572270	$6.6x10^{-3}$			

The long crack growth equation (propagation phase) may be written as in the form

$\frac{da}{dN} = 150(\Delta\gamma p)^{3.22}\ a$ .. shot peening crack growth equation μm/cycle **…4**

The behavior of long cracks in 0.4C medium carbon steel subject to shot peening may by described in fig.(3) for three different plastic shear strain namely 0.01 , 0.006 and 0.001 .

The S-N curve equation of the same material subjected to pure shear without peening can be illustrated in Fig (4).

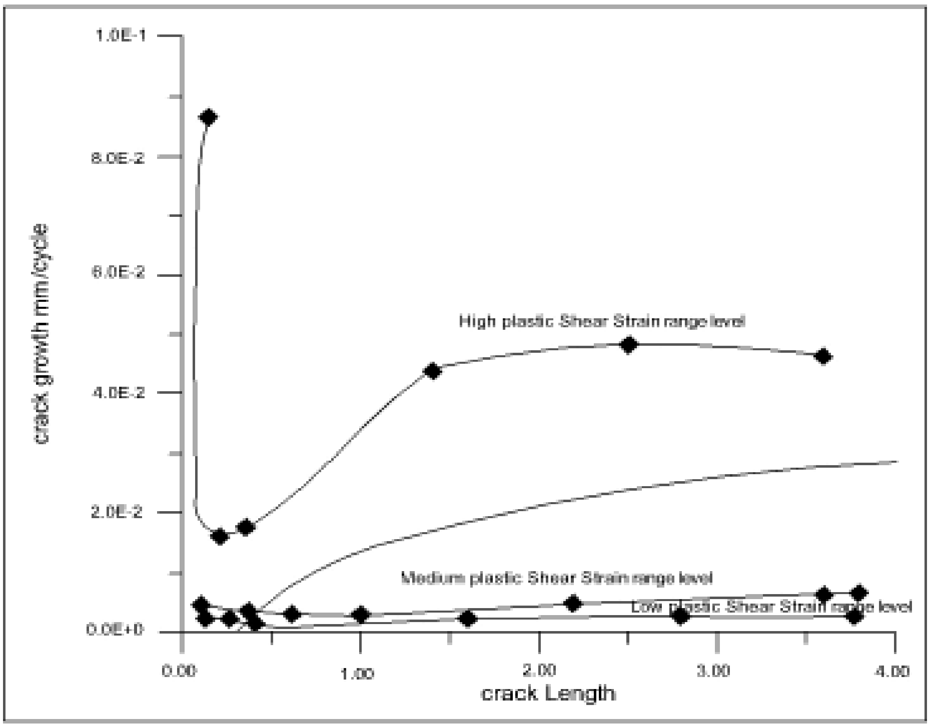

Fig (3) the behavior of long cracks under shot peening process strain levels under shot peening

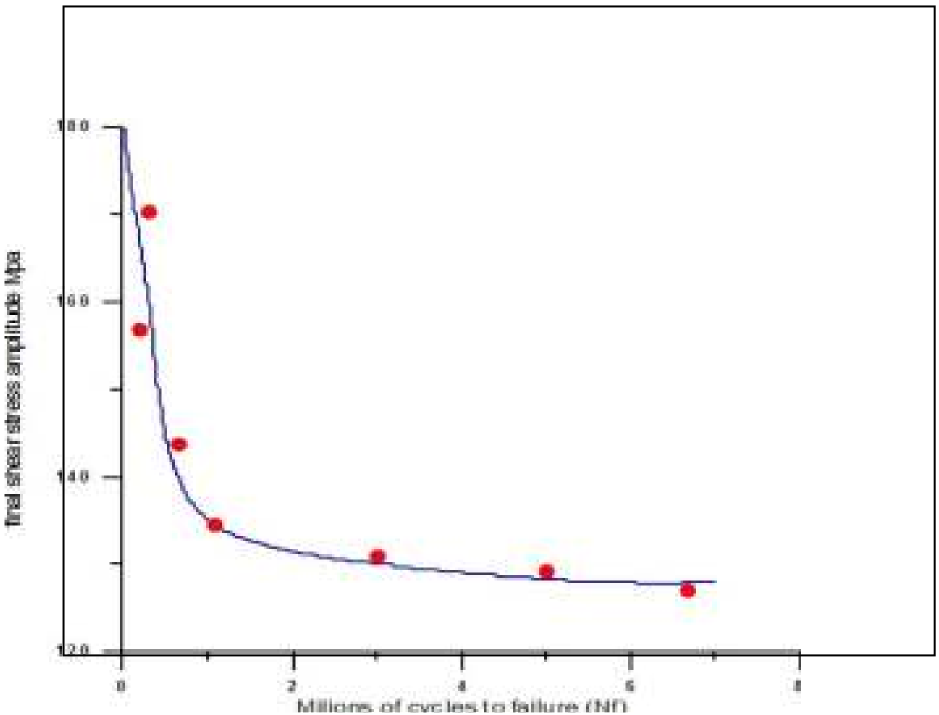

Fig (4) constant amplitude S-N curve for 0.4 C medium carbon steel subjected to pure shear. After [14]

Discussion

Table (3) shows a comparison between the behaviors of 0.4 C medium carbon steel for both cases (a) without shot peening (b) without peeing.

Table (3) Comparison of life for unshoted and shoted specimens under different plastic shear strain range level

Spec. No.	Plastic shear strain $(\Delta\gamma_p)$ *range*	without shot peening $\frac{da}{dN}$=17.4 $(\Delta\gamma_p)^{2.68}a$	
		N_f *cycles**	τ_f *MPa***
A1	0.01	109198	157
A2	0.006	429308	144
A3	0.001	52265460	127

Spec. No.	With shot peening $\frac{da}{dN} = 150(\Delta\gamma_p)^{3.22}a$		
	N_f *cycles**	τ_f *MPa**	Nshoted/Nunshoted
B1	152290	150	1.394
B2	788906	137	1.837
B3	252739269	125 unfailed	

* No. of cycles to failure were calculated by integrating the life equation with limits of integration from a=1μm (average Roughness) to a=4000 μm which is the failure definition)

**These values are obtained from the S-N curve (see Fig. 4)

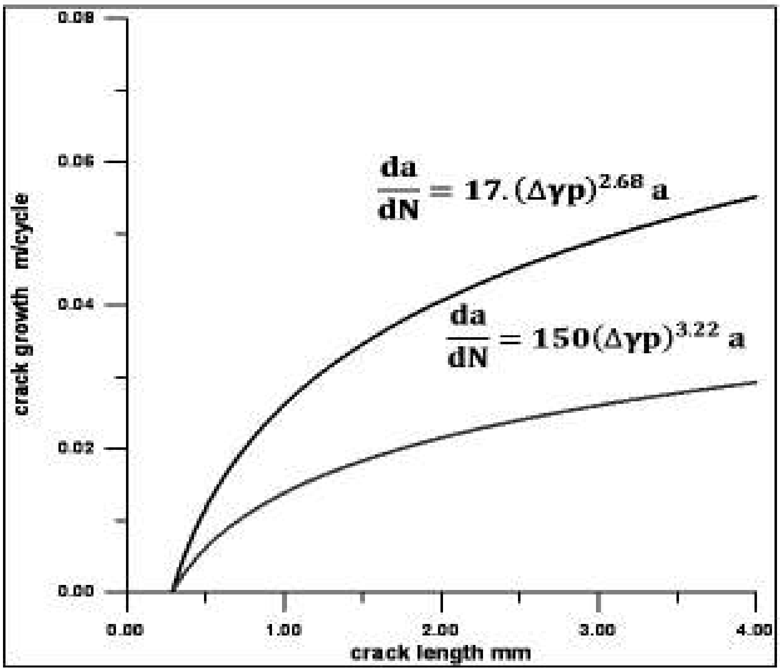

Fig (5) Comparison between crack length (mm) behaviors of long fatigue crack

Comparison between the crack growth rate for two conditions (without shot peening and with shot peening) is made on fig (5).It is observed that the shot peening increased fatigue strength and fatigue life . As the plastic shear strain range ($\Delta\gamma p$) decreased the life to failure increase. The shot peening treatment play an important role in fatigue behavior of the material. It is observed from the replication studies that the shot peening will arrest the surface cracks especially at low plastic shear strain levels [11] ,or due to the following reasons [11,12,13]. Several arguments other than a simple barrier to crack advance have been postulated for the cessation of growth .All of these are valid and interactive, but are also complex and difficult to formulate or apply [14] in the process of shot peening the compressive residual stress is created and increasing the surface hardness as result, the fatigue life is increased [2]

Conclusions:

1. Experimental results indicate significant increasing in 0.4C medium carbon steel fatigue life when shot peened.
2. The crack growth curves indicates the importance of compression residual field induced by shot peening treatment as barrier to long cracks crack initiation (short cracks) and cracks propagation (long cracks) .
3. The behavior of shot peening torsion fatigue crack growth in 0.4C medium carbon steel may be described by the equation : $\frac{da}{dN} = 150(\Delta\gamma p)^{3.22}$ **a μm/cycle**
4. The shot peening process play to reduce the plastic shear strain range ($\Delta\gamma_P$) which in turns the fatigue life increased.

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