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The use of double surface treatments to optimize the fatigue life of components made on structural steels

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Abstract

High intensity shot peening treatments have been combined with other different second treatments, such as low intensity shot peening, vibratory finishing and grit blasting with fine alumina powders, in order to optimize the fatigue life of a medium-alloyed, quenched and tempered, structural steel with a very high strength (2000 MPa). Single low intensity shot peening treatments using ceramic balls were also used with the same objective.
Roughness and residual stress profiles were measured, while the fatigue behavior was analyzed using a rotating bending fatigue equipment. Fracture surfaces were also analyzed in a scanning electron microscope (SEM) and the location of the fatigue crack initiation was detected.
Although the maximum stress in our fatigue tests is always applied on the surface of the specimen, the appropriate surface treatment combinations were able to optimize the fatigue response of the steel until the point where the fatigue crack initiated in the specimen interior (subsurface nucleation), due to the microstructural stress concentration provided by small alumina inclusions present in the microstructure of the steel. The amplitude of the stress intensity factor necessary to propagate fatigue cracks in the studied steel and the intrinsic stress intensity factor threshold, ΔK_{th}, were finally obtained.

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Keywords: double tretaments; shot peening; grit blasting; vibratory finishing; fatigue

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1. Introduction

Shot peening is widely used in the automotive and aerospace industries as a mechanical surface treatment to improve the fatigue life of metallic materials. It consists in blasting very hard, tiny, spherical balls onto the surface of the component to induce surface plastic deformation, the expansion of which is constrained by the adjacent deeper material. These surface treatments produce several effects (roughness modification, surface hardening, compressive residual stresses, but also surface defects) which, when properly controlled, can provide an important enhancement of the fatigue behavior of components subjected to dynamic loads [1-3].

In the other hand, different authors have demonstrated the possibility of increasing the fatigue life of components using double surface treatments [4-6]. Basically, double treatments consist in first applying a high intensity peening treatment, the major effect of which is to produce a deep region submitted to high compressive stresses, followed by a second surface treatment to reduce the roughness induced by the first treatment and mitigate the damage produced on the surface. Polishing, vibratory finishing, grit blasting and shot peening using smaller balls and lower intensities have been recognized to be effective second treatments.

Nomenclature

a	radius of the circle with a projected surface equivalent to the inclusion surface
h	distance from the specimen surface to the center of the inclusion
N	number of fatigue cycles
R	radius of the fatigue specimen
S	projected surface of inclusions
Z_0	depth submitted to residual compressive stresses at the end of the double treatments
σ_{max}	maximum tensile load acting on the surface of the fatigue specimen
ΔK_{th}	amplitude of the stress intensity factor fatigue threshold

2. Experimental procedure

2.1. Materials and processes

The study was performed on an AISI 4340 steel (0.41%C, alloyed with 1.9% Ni, 0.87% Cr and 0.24% Mo). The steel was supplied in bars with a nominal diameter of 16 mm. The bars were austenitized at 850ºC for 45 minutes, quenched in water and tempered at 200ºC for 2.5 hours. The heat treated steel had a yield strength of 1596 MPa, an ultimate tensile strength of 2000 MPa, and a tensile elongation of 11%.

The first surface treatment applied onto the different samples was shot peening using an Almen intensity of 19A and 100% coverage. This treatment was performed by means of a direct compressed air machine, using conditioned cut wire shots with rounded-off edges (CW, 670-730 HV, with an average diameter of 0.7 mm). Three types of secondary treatments were subsequently applied: vibratory finishing, grit blasting and low intensity shot peening using ceramic balls. Vibratory finishing was applied by placing the samples in a Rösler vibratory finishing machine using abrasive beveled ceramic cylinders with a length of 10 mm and a diameter of 3 mm (RP03/10 ZS), along with a SiC polishing paste (RSP 508 S) and water during 24 hours. On the other hand, grit blasting was applied by means of the same direct compressed air machine, using alumina powders with a grit size below 0.1 mm and an air pressure of 2 bars for 30 s and 60 s. The low intensity peening treatments were applied using ceramic balls (ZIRSHOT Y300) with a diameter of 0.3 mm and an air pressure of 2 bar in order to obtain an Almen intensity of 8A. Two different coverage degrees were employed in this case, 100 and 200%. Moreover, a single shot peening treatment using the same ceramic balls under the same Almen intensity of 8A was also applied as a comparison, using in this case coverages of 50% and 100%.