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An investigation into the effect of surface integrity on the fatigue failure of AISI 4340 steel in different drilling strategies

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ABSTRACT

DTH bits often fail because of fatigue fracture at the machined holes location. In order to understand the failure mechanism and improve the fatigue life of drill bits, the effects of drilling parameters and surface integrity on fatigue life of the AISI 4340 holed samples have been investigated. Three hole making strategies, including drilling with and without pre-drill and helical milling were utilized and compared. Results showed that the fatigue life increased by raising the cutting speed and decreasing the feed rate. The only exception was the two-fold variations of fatigue life versus feed rate when using pre-drill. Besides, the higher fatigue life was achieved in drilling with pre-drill, helical milling and conventional drilling, respectively. In fact, using pre-drill resulted in a better surface integrity compared to conventional drilling and higher work hardening relative to helical milling. Also, images of fractured surfaces represented radiation of discontinuous fatigue cracks from an initiation site near the hole middle plane.

1. Introduction

Fatigue strength is the most important mechanical property influenced by machined surface integrity due to the cracks initiation from the surface [1]. The term "surface integrity" is defined as the metallurgical, mechanical, and geometrical properties of the surface and sublayers. The most important aspects of surface integrity are surface roughness, texture, microstructure, microhardness, hardened layer thickness and residual stresses [2]. Currently, the effect of surface integrity on fatigue life is limited only to the correction factor of surface roughness (Ra), which mostly does not yield to the correct results and cannot be generalized to the real parts [3,4].

AISI 4340 low alloy steel is used in manufacturing of DTH[1] bits. Fatigue fracture near the machined holes and body tooth loss is one of the main failure mechanisms of these components [5]. Therefore, it is necessary to investigate the surface integrity of the drilled holes (as a stress concentration region) for improvement of the DTH fatigue life.

There are several hole making methods, including conventional drilling (one-step or multi-step) and helical milling [6]. In drilling, cutting is done using negative rake angle and applying high axial pressure. Therefore, the tool's higher vibration and continuous chips create surface irregularities, which are suitable locations for fatigue cracks initiation [7]. Also, severe plastic deformation in the cutting region increases the hardness and creates compressive residual stresses in the surface and sublayers. Such a hardened layer prevents the initiation and propagation of fatigue cracks [8]. Besides, the temperature increasing in the cutting region (higher than austenitization temperature) followed by rapid cooling leads to the formation of a martensitic deformed film, named

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[1] Down the hammer.

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"white layer". This layer has high tensile residual stresses with many tiny surface cracks and a reducing effect on fatigue strength [9]. The mentioned phenomena are more severe in drilling of hard steels due to the lower heat transfer and higher strain hardening [10]. In the following, some studies related to the effect of surface integrity on fatigue life in hole making processes are reviewed.

Sun et al. [11] compared the effects of conventional drilling and helical milling on the fatigue performance of Ti-6Al-4 V and Al 2024-T3. They concluded that helical milling leads to longer fatigue life due to the lower plastic work. The surface roughness also intensified the effects of these processes.

Davis et al. [12] compared two methods of machine tapping and thread milling to produce threaded holes on a BS S97 alloy steel workpiece. They showed that the fatigue life of the specimen with a threaded hole enhances despite the better surface roughness in the tapping technique. This phenomenon was explained by the formation of compressive residual stresses in threading due to the plastic work.

Liu et al. [13] studied the effect of hole surface integrity on fatigue life of 2A12T4 specimens using a finite element simulation. The results showed that the fatigue life of the holed coupons diminishes by increasing the size of surface imperfections.

Chakherlou and Vogwell [14] studied the effect of hole expansion process on fatigue strength of fastener holes both experimentally and numerically. The results showed that the fatigue life of a cold worked sample is higher than that without the plastic work. This life enhancement was greater in lower alternating stress. However, this improvement had some exceptions like the study done by Boni et al. [15].

Everett [16] investigated the effect of hole making process on Al 2024 samples used in aircraft wings. The results showed that the average fatigue life of holed specimens created by mechanical methods is 3 times more than chemically polished ones. This was because of higher compressive residual stresses. Also, the cavities created by chemical polishing were the most suitable region for crack initiation and growth.

Ralph et al. [17] compared various hole making methods based on the fatigue life on Al 2024 samples with the central hole. The results indicated that drilling with worn tool increases the crack initiation cycles due to the higher compressive residual stresses around the hole. But this effect was neutralized by increasing the surface roughness. On the other hand, the crack propagation cycles were up to 50% higher when using a new tool. In fact, a worn tool formed larger tensile residual stresses farther away from the area of compressive residual stresses to keep the balance. Therefore, the crack propagated faster after passing the area with compressive residual stresses.

Review of previous studies reveals that many activities such as mechanical and chemical polishing or using cold work have been done to improve the fatigue life of holed specimens [18]. These processes require higher time (and cost) and are not proper for hardened workpieces or mass production. A better way of fatigue life enhancement is to optimize drilling process and improve the hole surface integrity. However, lack of a comprehensive research on the effect of hole making process and its parameters on fatigue strength, especially in hard steels, is evident.

The purpose of this study is to develop a relationship between drilling process parameters, surface integrity and fatigue life of AISI 4340 hardened steel. Accordingly, the effect of drilling parameters is explored on the surface integrity of the holes created by three strategies, including conventional drilling, drilling with pre-drill and helical milling. Then, the influence of process parameters and the originated surface integrity are studied on fatigue life using fatigue test specimens.

2. Materials and methods

Three hole making strategies, including conventional drilling with and without pre-drill and helical milling were employed. Fig. 1 illustrates kinematic of the mentioned methods. The experiments were conducted on AISI 4340 steel coupons. The specimens were hardened up to 450 ± 5 Vickers in two steps. Initially, the temperature was elevated up to 870 °C in vacuum furnace slightly and

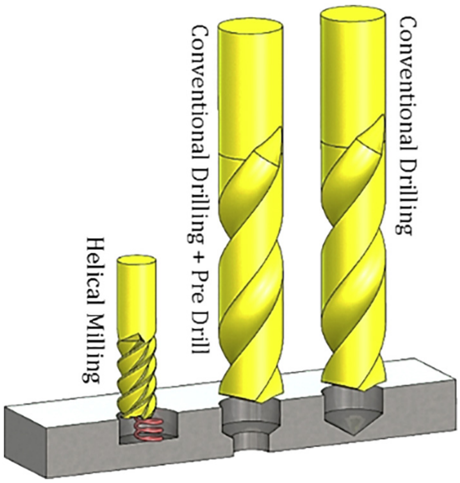

Fig. 1. Kinematics of hole making strategies.