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# Fatigue Performance in Grinding and Turning: An Overview

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***Abstract:*** *This paper analysis the influence of Abrasive Flow Machining (AFM), Turning and Grinding on fatigue performance of Fe250. Surface condition has a strong effect on fatigue life, and that most surfaces produced by conventional manufacturing operations such as machining and forging have poor fatigue behavior than polished surfaces commonly used for laboratory specimens. It is found that the surfaces produced with different machining process and having the same surface roughness having different fatigue performances. High –cycle fatigue data was obtained for Fe 250 using three types of machining process viz, AFM, Turning and Grinding .S-N curve is plotted for the samples obtained with all the three process. It was found that the samples produced with AFM having the highest fatigue life.*

***Keywords:*** *Abrasive flow machining, Fatigue life, Surface roughness, Turning, Grinding.*

## I. Introduction

The achievement of high quality, in terms of work piece dimensional accuracy, fatigue strength, surface finish, less wear on the cutting tools, economy of machining are the main and effective challenges of modern metal cutting and machining industries. Fatigue performance of materials will be reducing when they are subjected to various machining process. Fatigue cracks in these components usually may be initiated in geometrical features, which cause local stress concentrations, in most cases at the surface. It is well known that the fatigue life of a machine component depends strongly on its surface layer condition. Fatigue crack nucleation and propagation, in most cases, can be attributed to surface integrity, which includes surface roughness, structure and stress conditions of the surface layer. The importance of surface integrity increases with increasing loads, temperature and frequency. This becomes critical for high strength steels, which are more sensitive to stress concentration.

The surface roughness and surface texture of a machine component is decided mainly by finishing operations. Machining can be used to produce a wide range of mechanical components such as gears, cams, shafts, axles and others, which are continuously subjected to cyclic loads. During the process of turning the surface generated is influenced by several variables: steel properties (elastic and plastic deformations), tool material and geometry, vibration of cutting tool, cutting speed, feed, depth of cut, lubricant, etc. During machining, the surface layer is subjected to elastic-plastic deformation and heating, which result in structural changes, strain hardening and residual stresses, while irregularities may appear, creating surface roughness. All these factors will lead to reduce fatigue life in Turning operations. Whereas girding is a micromachining process and it results in (i) increased hardness of the surface layer, (ii) more compressive residual stresses (iii) Changes in material property at the surface. In grinding due to work hardening the initiation of crack and crack propagation is little delayed. This will result in increase in fatigue life. However work hardening will reduce the fatigue life. As a result of these factors the fatigue will not have much improvement during the grinding process.

In AFM any surface defects present in the surface of the work piece will be removed. It will also remove residual stresses present in the work piece. During AFM no thermal stresses or work hardening effects will be developed within the material. Present study is to assess the fatigue performance during AFM and compare Fatigue performance in AFM with the turning and grinding operations.

## II. PREVIOUS RESEARCH

A damaged region is produced on the surface of metal which is different from the inner surface of the material as a result of machining [1]. During machining, the surface layer is subjected to elastic-plastic deformation and heating, which result in structural changes, strain hardening and residual stresses, while irregularities may appear, creating surface roughness. The influence of cutting parameters (cutting speed, feed rate and depth of cut) on surface quality, and consequently on roughness surface, is well studied. A large number of analytical and experimental studies have been conducted on surface roughness of steels in machining operations. These research developments have been performed with the objective of optimizing the cutting conditions to obtain surface finish [2]. Davim [3] studied the influence of cutting conditions on the surface finishing obtained by turning. According to this paper, the cutting speed had the greatest influence on the roughness followed by the feed rate. The depth of cut had no significant influence on the roughness. Similar results were found by Feng (2001) that also observed that in addition to feed rate, nose radius, work material and speeds, the rake angle has a significant influence on the surface roughness [4].

The fatigue strengths of machined and as-cast surfaces of ferritic SG iron have been compared by Starkey and Irving [5]. They found endurance of machined specimens was found to be higher than that of as-cast surfaces. Micro pores initiated failure in the machined specimens, whereas surface irregularities or dross defects initiated cracks from the as-cast surface.

Taylor and Clancy have compared the fatigue limit of AISI 4140 using four types of machined surfaces produced by polishing, grinding, milling and shaping[6]. The residual stress was eliminated by heat treatment. They found that fatigue limit of ground surfaces decreased when compared to polished specimens, that is, the fatigue limit decreased with increasing surface roughness. However, a comparison of the fatigue limits of the specimens with ground surfaces with those of milled surface specimens showed an opposite tendency, that is, an increasing of fatigue limit with increasing surface roughness. Besides, there was not observed difference between fatigue limits of the polished and fine milled specimens, even though surface roughness values were quite different.

The effects of surface roughness on cracking initiation and S-N curves of a Ni-Cr-Mo steel were studied by Itoga et al. [7]. Surface roughness was the most important influencing factor in short life regime, and the fatigue life was found to decrease with increasing surface roughness. On the contrary, in long life regime, surface roughness exerted no influence on fatigue life, because cracks nucleated at inclusions and grew inside the specimens. Arola and Williams (2002) found that the high-cycle fatigue life of machined specimens of AISI 4130 steel is surface-texture dependent, and that the fatigue strength decreased with an increase in surface roughness from 2 to 6 µm. On the other hand, an increase in fatigue life occurred with increasing surface roughness under low-cycle fatigue. It was also found that the notch sensitivity of these machined specimens did not change significantly with surface roughness. The effects of surface roughness, work-hardened layer and humidity on S-N curves of high strength AISI 4340 steel was studied by Nakajima et al. [8]. Buff-finished and electro-polished specimens with two different surface conditions were prepared. Fatigue lives were longer in the buff-finished than in the electro-polished specimens, due to the presence of a work-hardened layer.

Becker studied the deformation of polycrystals and showed that the surface roughness increases with plastic strain [9]. Under fatigue loading, it was found that the surface roughness increased with fatigue life, and the deformation is localized in some specific places, where micro-cracks are nucleated .As shown, the importance of both surface roughness and integrity is well recognized, with many experimental and analytical models relating these characteristics with fatigue life. However, there are only few results in literature that show the influence of machining cutting parameters on fatigue life of commercial steels. In general more attention is given on the influence of grinding on fatigue strength. However, in these days materials can be machined and finished with newly developed tools, eliminating the need for other finishing operations. Thus, it is necessary to know the relationship between fatigue parameters and cutting operations. In the present study, the influence of cutting speed, depth of cut and feed rate on the fatigue endurance of turned specimens of commercial AISI 4140 steel is analyzed.

## III. EXPERIMENTAL PROCEDURE

In this investigation the AISI4140 steel was used as the work material. Whose chemical. This material was supplied in the form of cylindrical bars. This bar is turned into the dimensions as shown in fig (1)

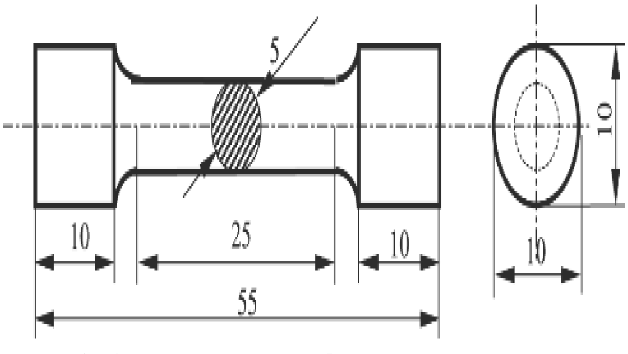
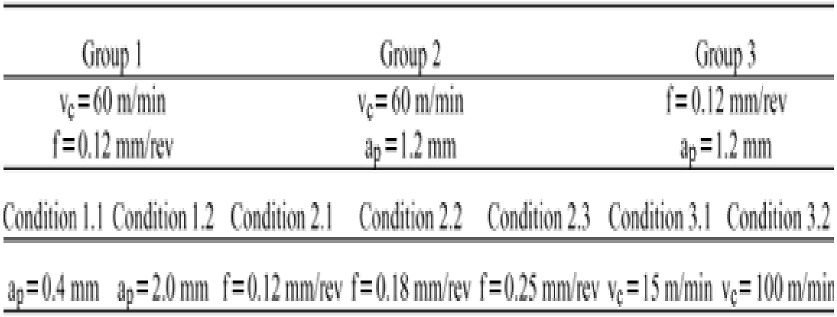


Fig 1 1.1. Fatigue analysis in Turning

The specimens received, after heat treatment, turned to the configuration shown in Fig. 1.The cutting parameters selected is shown in table 1. All these conditions are used in finishing turning operations. They were chosen in order to have specimens with three different feed rates (group 2, conditions 2.1 to 2.3), three different depths of cut (group 1, conditions 1.1, 1.2 and 2.1), and three different cutting speeds (group 3, conditions 3.1, 3.2 and 2.1). Thus, each group has two constants and only one variable cutting parameter. These specimens will be designated according to their condition number hereafter (Ex.: condition 1.1, etc). The turning process was carried out using a CNC lathe.

**Table 1**



| Group 1 | | Group 2 | | | Group 3 | |
|---|---|---|---|---|---|---|
| $v_c$=60 m/min<br>f=0.12 mm/rev | | $v_c$=60 m/min<br>$a_p$=1.2 mm | | | f=0.12 mm/rev<br>$a_p$=1.2 mm | |
| Condition 1.1 | Condition 1.2 | Condition 2.1 | Condition 2.2 | Condition 2.3 | Condition 3.1 | Condition 3.2 |
| $a_p$=0.4 mm | $a_p$=2.0 mm | f=0.12 mm/rev | f=0.18 mm/rev | f=0.25 mm/rev | $v_c$=15 m/min | $v_c$=100 m/min |

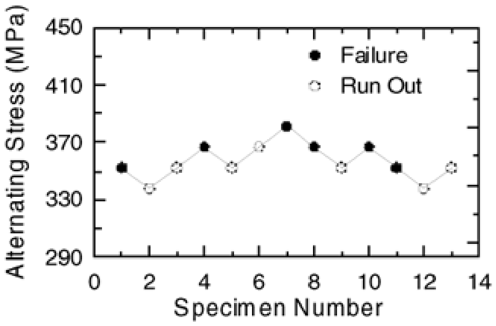


**Fig 2 .Stair case fatigue test - Condition 1.1**

The experimental tests of the specimens machined according to condition 1.1 were performed with alternating stress varying from 323.15 to 381.09 MPa fig (2)The fatigue limit of this condition was found to be equal to 287.96 ± 21.54MPa.

The stair case test of the specimens of the condition 2.1 with alternating stress varying from 395.97 to 424.54 MPa is showed in fig (3). The fatigue limit for this condition 2.1 was found to be equal to 366.84 ± 16.32 MPa.

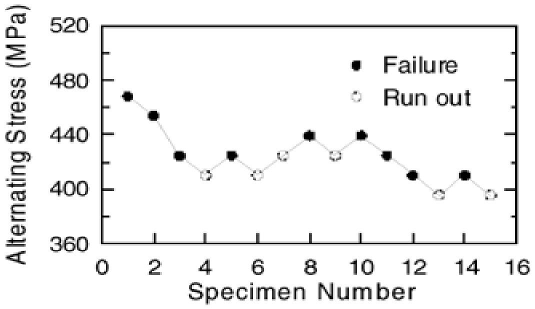


**Figure 6. Stair case fatigue test - Condition 2.1.**

**Fig 3.Stair case fatigue test - Condition 2.1**

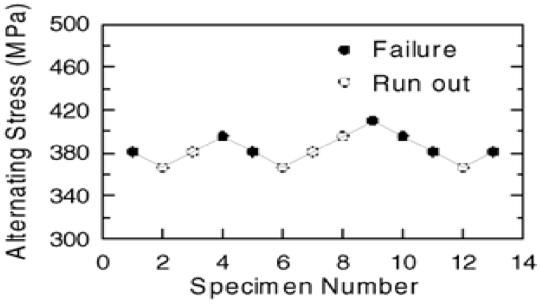


**Figure 7. Stair case fatigue test - Condition 3.1.**

**Fig 4 .Stair case fatigue test - Condition 3.1**

The stair case test of the specimens of the condition 3.1 was performed using alternating stresses from 366.66 vto 410.06MPa, as shown in fig (4) The fatigue limit of this condition 3.1 was equal to 341.10 ± 13.72 MPa. The influence of depth of cut (ap) on fatigue limit is shown in fig (5)The fatigue limit of AISI 4140 steel increases almost 18% with increasing depth of cut from 0.4 to 1.2 mm. Further increase in depth of cut to 2.0

mm has no pronounced influence on the average fatigue limit of this steel. However, the dispersion of the fatigue limit increases with increasing depth of cut. The influence of depth of cut on fatigue limit is similar to those observed in Fig. 2.

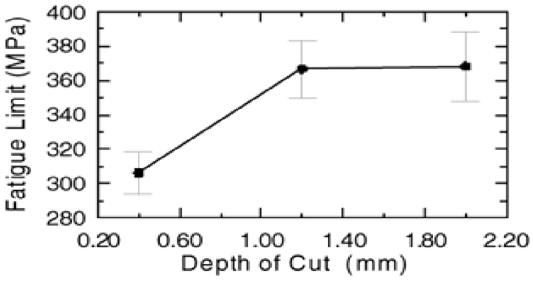


**Fig 5 .Influence of depth of cut on fatigue limit**

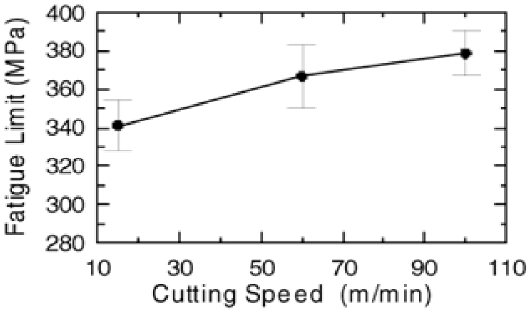


**Fig 6 .Influence of cutting speed on fatigue limit**

The fatigue limit of AISI 4140 steel increases almost linear with increasing cutting speed (vc), as shown in the Fig(6) This result was expected, since increasing cutting speed leads to smaller roughness values. Besides, the cutting speed had no influence on the dispersion of the fatigue limit.

The fatigue limit of the AISI 4140 steel is only slightly influenced when the feed rate (f) is increased from 0.12 to 0.18 mm/rev, as shown in fig (7). A sharp decrease in fatigue limit is observed when the feed rate is further increased to 0.25 mm/rev. It was previously shown that surface roughness increased almost linear with increasing feed rate. Thus, it was expected a similar behavior between fatigue limit and feed rate. It becomes evident that fatigue limit is determined not only by roughness values. Residual stresses originated by machining are also important.

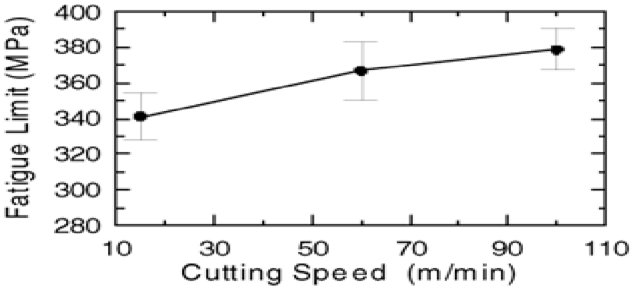


**Fig 7 .Influence of cutting speed on fatigue limit**

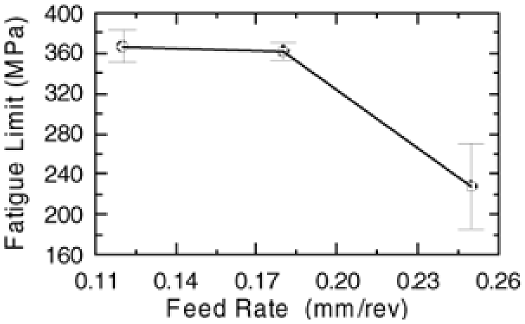
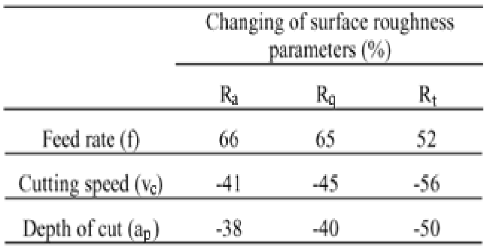


**Fig 8 .Influence of feed rate on fatigue limit**

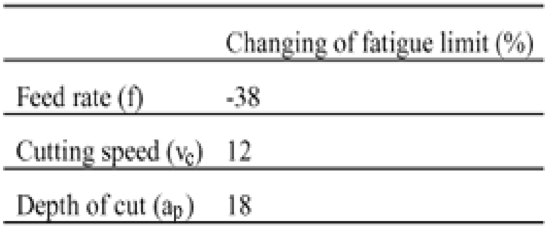
The variation of all measured fatigue limits with cutting parameters is summarized inTable(5)The most influent parameter on fatigue limit is the feed rate. This is in accordance with the surface roughness results (Table4) However, the changes of fatigue limits with cutting parameters are quite lower than that observed previously by the roughness parameters. Thus, only the roughness parameters can not explain the changes of fatigue limits of this steel. The fatigue endurance of machined component depends strongly on its surface layer condition. During the machining, the surface layer is subjected to several phenomena, which result in structural changes, strain hardening and residual stresses, while irregularities may appear, creating surface roughness. The fatigue limit is determined by all these parameters.

**Table 3.Changing fatigue limit with cutting parameters**



| | Changing of surface roughness parameters (%) | | |
|---|---|---|---|
| | $R_a$ | $R_q$ | $R_t$ |
| Feed rate (f) | 66 | 65 | 52 |
| Cutting speed ($v_c$) | -41 | -45 | -56 |
| Depth of cut ($a_p$) | -38 | -40 | -50 |

**Table 4.Changing fatigue limit with cutting parameters**



| | Changing of fatigue limit (%) |
|---|---|
| Feed rate (f) | -38 |
| Cutting speed ($v_c$) | 12 |
| Depth of cut ($a_p$) | 18 |

The influence of roughness surface on fatigue limits of all machined and polished specimens is summarized in fig(8)The fatigue limit decreases almost linear with increasing roughness surface. This tendency is not obeyed when the specimens without residual stress (heat treated) is included. Besides, the highest value of fatigue limit was reached in the polished specimens, without relief stress. However, relief stress heat treatment in machined specimens can substantially raise their fatigue endurances. If machined specimens with better initial fatigue limit than that previous utilized would stress relief heat treated, a higher fatigue limit could be reached. Thus, it could be cheaper to produce components using only commercial machining parameters and stress relief heat treatment, than polished specimens.

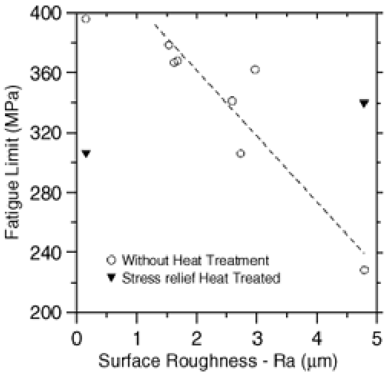
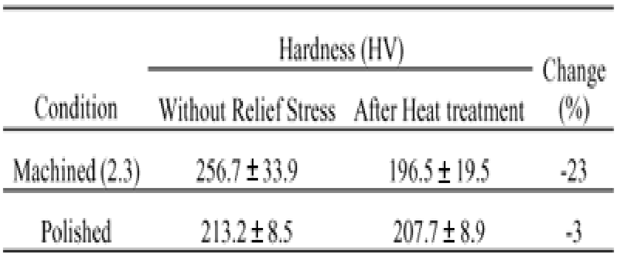


**Fig 9 .Summary of fatigue limits of all analyzed**



| Condition | Hardness (HV) Without Relief Stress | After Heat treatment | Change (%) |
|---|---|---|---|
| Machined (2.3) | 256.7 ± 33.9 | 196.5 ± 19.5 | -23 |
| Polished | 213.2 ± 8.5 | 207.7 ± 8.9 | -3 |

**Table 4. Hardness (HV) of specimens of AISI 4140 steel**

This paper presents the influence of commercial cutting parameters during machining on fatigue limits of AISI 4140 steel. Fatigue rotating bending tests were performed on steel specimens with zero mean stress at room temperature. The fatigue limit decreases with increasing roughness parameters. The influence of cutting parameters on fatigue limits is lower than that on surface roughness. The relation between residual stresses, strain hardening and roughness surface plays a dominant role. Stress relief heat treatment causes an increase of fatigue limit of machined specimens with high roughness parameters and a decrease in polished specimens. The softening of both specimen types (polished and machined) caused by the heat treatment is not similar. The sharp increase of fatigue limit of machined specimens is due to elimination of residual stress, which overcome the effect of surface layer softening.

## 1.2. Fatigue analysis in Grinding

In order to study the fatigue damage of AISI 4140, rotating bending fatigue tests of EP-0, EP-3 and EP-15 specimens were carried out. Here, EP-0 means the specimen finished by the grinding, EP-3 and EP-15 are the specimens whose 3 and 15 Pm surface layer were electropolishedafter the grinding, respectively. The main conclusions from analysis of fatigue data may be summarized as
follows.

**(1)** The fatigue strength of EP-0 exhibited large scatter and it tended to drop again in the long-life field in excess of 107 cycles. The fracture origin in such a long life field was principally inner defects. At around the fatigue limit stress at 107 cycles, two different fracture modes, surface fracture and inclusion governed inside fracture, were mixed together.

**(2)** Fatigue strength of EP-15 was dramatically decreased and the scatter in S-N plots is very small when compared to the EP-0. All the cracks of EP-15 were initiated from the surface even at the stress below the fatigue limit at 107 for EP-0.

**(3)** S-N plots for EP-3 exhibited large scatter, but the range of scatter is smaller than EP-0. This may come from the decreased scatter in geometric shape of the surface by electro polishing. On the other hand, the difference in the mean value of S-N plots between EP-0 and EP-3 is not large. removing 3 Pm surface layer ,the drop in fatigue strength due to the reduced hardened layer and the increase in fatigue strength derived from the decreased surface roughness may balance.

**(4)** Considering above experimental results synthetically, it can be concluded that the peculiar S-Characteristics observed in ground specimen results from the surface strengthened layer (work hardening and residual stresses) due to grinding. Those experimental facts indicates that the re-drop in fatigue strength in super long-life field frequently reported in high-strength material is not necessary the proper characteristics of material itself.

## IV. CONCLUSION

From the above results it can be concluded that the fatigue strength generally depends on the surface finish.But the surface finish alone does not improve the fatigue strength. This paper presents the influence of commercial cutting parameters during machining on fatigue limits of AISI 4140 steel. Fatigue rotating bending tests were performed on steel specimens with zero mean stress at room temperature. The fatigue limit decreases with increasing roughness parameters. The influence of cutting parameters on fatigue limits is lower than that on surface roughness. The relation between residual stresses, strain hardening and roughness surface plays a dominant role. Stress relief heat treatment causes an increase of fatigue limit of machined specimens with high roughness parameters and a decrease in polished specimens. The softening of both specimen types (polished and machined) caused by the heat treatment is not similar. The sharp increase of fatigue limit of machined specimens is due to elimination of residual stress, which overcome the effect of surface layer softening.

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