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Relationship between Fatigue Strength and Surface Characteristics for Machined Parts of Heat-resistant Alloy of Cr-Mo-V steel

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Abstract

Cr-Mo-V forged steel is a material suitable for mechanical parts used in high-temperature and high-pressure environments. In general, the mechanical parts made of Cr-Mo-V forged steel are fabricated by cutting the workpiece in the final stage of the manufacturing process. Surface characteristics of the resulting parts likely affect their fatigue life. Thus, it is important to understand the cutting characteristics of Cr-Mo-V steel to efficiently produce the mechanical parts used in the severe environments. However, few studies have been carried out to investigate the cutting characteristics of Cr-Mo-V forged steel. Moreover, there is little information available on the influence of the surface characteristics on its fatigue life. In the present study, we turned the workpieces of Cr-Mo-V forged steel and stainless-steel SUS304 under various turning conditions, and investigated the work hardened layers of the resulting parts. The experimental results showed that the work hardened layers for the Cr-Mo-V steel is hardly generated compared to those for the stainless-steel SUS304. On the basis of the experimental results described above, we produced the test pieces of Cr-Mo-V steel having few work hardened layers with various surface roughness to evaluate their fatigue life. The evaluation was performed by changing stress amplitude in the range of 300-400 MPa, which revealed that the fatigue life was more than 10^4 cycles in that range of stress amplitude. As a result, it was found that the fatigue life is affected by surface roughness when the stress amplitude is low. In such stress amplitude, the fatigue life becomes longer as the surface is smoother. Moreover, fatigue cracks are generated at the concave portions of the turning marks when the surface is rough.

Keywords: Heat-resistant Alloy, Cr-Mo-V steel, Machining, Surface roughness, Work hardened layer, Fatigue life

1. Introduction

Cr-Mo-V forged steel is a material suitable for mechanical parts used in high-temperature and high-pressure environments, such as turbine rotors and turbine valves in power plants [1, 2]. In general, parts made of Cr-Mo-V forged steel are manufactured by cutting the workpiece in the final stage of the manufacturing process. Thus, it is important to understand the cutting characteristics of Cr-Mo-V forged steel to efficiently produce parts with high accuracy. However, few studies have been carried out to investigate cutting the characteristics of Cr-Mo-V forged steel. Moreover, there is little information available on the influence of the surface characteristics on its fatigue life.

In our previous study, we investigated tool wear and chip formation when cylinders made of Cr-Mo-V forged steel were turned by a CNC lathe under various conditions [3]. In the present study, we turned the workpieces of Cr-Mo-V forged steel under various turning conditions to investigate the work hardened layers of the resulting parts. Moreover, we produced the specimens of Cr-Mo-V steel having few work hardened layers with various surface roughness to evaluate the fatigue life depending on the surface roughness.

2. Workpiece material

The workpieces used in this study were cut out from the blank of a turbine rotor made from Cr-Mo-V steel. The blank was made by casting followed by forging by Pacific Steel Mfg. Co., Ltd., Japan. It was thus assumed that the material properties of the workpieces used in our experiment were the same as those of the actual turbine rotor. In this study, we also machined the stainless steel SUS304, as defined by Japan Industrial Standards, for comparison. The chemical components of the Cr-Mo-V forged steel are shown in Table 1.

Table 1. Chemical components of Cr-Mo-V steel [wt %].

C	Si	Mn	P	S	Ni	Cr	Mo	V
0.31	0.08	0.78	0.007	0.002	0.41	1.10	1.13	0.22

3. Investigation of work hardened layers

We investigated the work hardened layers generated by turning at various cutting conditions using a cermet tool. The radius of the tip of the tool was 0.4 mm. The workpieces were prepared as cylinders with 50 mm diameter and 20 mm thickness. The turning conditions and the specimen names are shown in Table 2. The cutting speed was 50 m/min for the cutting of all specimens.

Table 2. Turning conditions and specimen names.

Feed rate [mm/rev]	Depth of cut [mm]		
	0.3	0.5	1.0
0.08	B1	B2	B3
0.20	B4	B5	B6
0.31	B7	B8	B9

The turned specimens were divided into quarters, as shown in Fig. 1. The cut surface of each specimen was polished to a mirror surface to test Vickers hardness. The positions of the testing of the Vickers hardness are shown in Fig. 1, and the load of the testing was 490 mN. The testing was conducted three times for each position, and the measurement results were averaged.

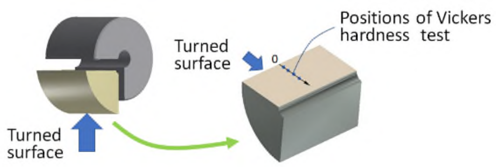
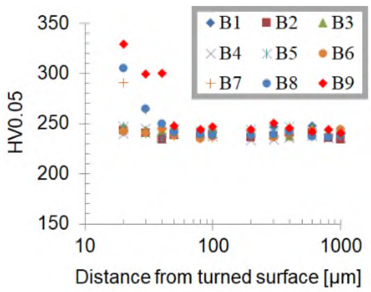
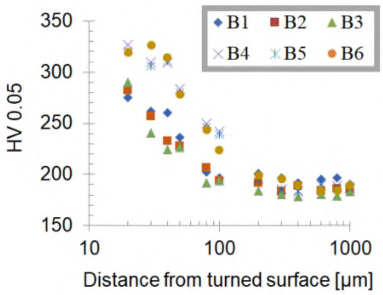


Figure 1. Specimen for Vickers hardness test.

Figure 2 shows the experimental results that revel the depth of work hardened layers generated in the subsurface of Cr-Mo-V and SUS304 specimens under various turning conditions. As shown in Fig. 2, the work hardened layers for the Cr-Mo-V steel are not found at a feed rate of less than 0.2 mm/rev although those for SUS304 are generated at the depth of up to approximately 100 µm. Even at a feed rate of 0.31 mm/rev, the depth of the work hardened layers is only 40 µm for Cr-Mo-V steel. To observe the metallographic structures of the turned surfaces, we polished and etched the cut surfaces of the Cr-Mo-V steel specimens. The observation shows that the plastic deformation at the depth of up to 40 µm for the specimen obtained by a feed rate of 0.31 mm/rev. Therefore, the generation of the work harden layers mainly results from the plastic deformation by turning



(a) Cr-Mo-V steel



(b) Stainless steel SUS304

Figure 2. Work hardened layer measured by Vickers hardness test.

4. Fatigue test

We performed the fatigue test for the turned Cr-Mo-V steel specimens with various surface roughness, as follows. As shown in Fig. 2, the work hardened layers are not found at a feed rate of less than 0.2 mm/rev for the Cr-Mo-V steel. By turning under such conditions, we can make the fatigue specimens with various surface roughness without the work hardened layers. This allows us to investigate the fatigue life only depending of surface roughness. Thus, the specimens were made by the feed rates of 0.08, 0.12, and 0.16 mm/rev. This realized the specimens with the average surface roughnesses Ra of 0.90, 1.31, and 2.25 µm without the work hardened layers. The shape of the specimens was dumbbell with a length of 200 mm. The surface roughness was measured using the three dimensional measuring instrument employing a laser probe. The fatigue test was conducted under a pulsating tension condition with the stress amplitudes of 300, 350, and 400 MPa. The frequency of the stress was 15 Hz. The testing was terminated at the number of the stress cycle of $1X10^6$ when the specimen was not broken.

Figure 3 shows the experimental results, showing the relationship between the number of the stress cycle and the stress amplitude for the specimens with various surface roughness. In Fig. 3, the arrow represents an unbroken specimen by the number of the stress cycle of $1X10^6$. As shown in Fig. 3, when the stress amplitude is 400 MPa, the fatigue life seems to be independent of the surface roughness. The observation showed the plastic deformation at the broken portion of the specimens. However, when the stress amplitude is 300 MPa, the fatigue life become dependent on the surface roughness. The close observation of the broken specimen shows that the fracture appeared to occur at the concave of the tool marks generated by tuning. Thus, it is considered that the fracture was caused by the stress concentration at the concave portions of the tool marks when the stress amplitude was 300 MPa.

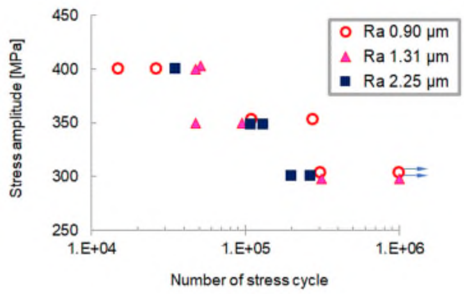


Figure 3. Fatigue tests for Cr-Mo-V steel with various surface roughness.

5. Conclusions

We turned Cr-Mo-V forged steel and stainless-steel SUS304 under various turning conditions. The experimental results showed that the work hardened layers for the Cr-Mo-V steel is hardly generated compared to those for the SUS304.

We produced the specimens of Cr-Mo-V steel having few work hardened layers with various surface roughness to evaluate their fatigue life. The evaluation was performed by changing stress amplitude in the range of 300-400 MPa. As a result, when the stress amplitude is low, the fatigue life becomes longer as the surface is smoother. Moreover, fatigue cracks are generated at the concave portions of the turning marks when the surface is rough.

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