Experimental study of ultrasonic rolling processing

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Abstract. The ultrasonic vibration device and the rolling pressure measurement device are added on the ordinary rolling equipment, which form the ultrasonic rolling equipment. Due to the ultrasonic impact, ultrasonic rolling processing can obtain better surface quality and surface reinforcement than ordinary rolling processing. The experimental results show that the process parameters such as rolling pressure, rolling speed and feed volume effects obviously on the surface roughness and surface micro-hardness of the work piece ultrasonic rolled. In ultrasonic rolling processing, a relatively small rolling pressure can be used to obtain satisfactory processing results, avoiding the surface defects caused by large rolling pressure. Ultrasonic vibration frequency is generally 20kHz. And the vibration amplitude is generally 20 μm. The right combination of process parameters and the use of coolant provide the best process results.

1. Introduction
Ultrasonic rolling processing is a process technique to improve the overall performance of the work piece surface [1-6]. It is to add ultrasonic vibration device on the ordinary rolling equipment, apply pressure to the work piece surface and attach the ultrasonic frequency mechanical vibration, so as to realize the ultrasonic impact on the work piece surface in the rolling process. The results show that the selection of appropriate process parameters such as rolling pressure, rolling speed and feed can eliminate the surface defects produced by pre-processing, reduce surface roughness and improve the surface micro-hardness.

2. The ultrasonic rolling processing principle
Rolling strengthen of the surface of the work piece, the surface metal at room temperature to produce a certain plastic deformation, can improve the surface micro-hardness of the work piece, produce the surface residual pressure stress, enhance the wear resistance and fatigue strength of the work piece.

The ultrasonic rolling processing is an organic combination of ordinary rolling and ultrasonic processing technology. If the process parameters are appropriate, ultrasonic rolling processing can produce better surface quality and surface reinforcement than ordinary rolling processing [7-10]. In the ultrasonic rolling process, the rolling body of ultrasonic device, as a rolling tool, along the direction of the surface line to apply a certain ultrasonic frequency mechanical vibration, so that the rolling body impact contact work piece surface. As the roller with a certain feed speed process entire work piece surface, the surface of the work piece produces mechanical cold hardening, greatly improving the hardness and wear resistance of the surface, and reduce the roughness of the surface. Compared with the traditional rolling process, ultrasonic rolling processing has a series of advantages such as lower rolling pressure, lower friction, further reduction of surface roughness value, smoother surface, increased surface wear resistance. The ultrasonic rolling is particularly suitable for surface
reinforcement of low-stiff parts such as slender shafts and thin wall parts, so it is increasingly valued and popularized. Figure 1 is a schematic of the ultrasonic rolling.

3. The ultrasonic rolling equipment
In order to achieve ultrasonic rolling for cylindrical parts, the roller and work piece should have an appropriate combination of motion. We install ultrasonic rolling set on the knife rack of a normal lathe to get the desired combination of motion. Figure 2 is a sketch of ultrasonic rolling equipment. The roller is a part that directly exerts rolling pressure on the surface of the work piece. A vibration system consisting of piezo-ceramic ultrasonic transducer and step-type transpose bar is clamped on the knife rack of a normal lathe, and the roller is embedded in the front end of the transpose bar. The vibration system follows the knife rack for feed motion along the axis of the work piece, while the vibration system also drives the roller to perform a ultrasonic impact on the work piece surface along the direction of the radius of the work piece.

The work piece is holden in the lathe chuck for swing movement, to ensure that the entire surface of the work piece can be evenly ultrasonic rolling processing. Throughout the process, the oil is poured into the rolling processing area as a lubricated coolant to reduce friction between the roller and the work piece surface and to reduce the temperature of the processing area. Figure 3 is an ultrasonic rolling machine, and the S-shaped element in the photo is a strain force sensor that measures the rolling pressure.
4. The ultrasonic rolling processing improves the surface quality

Processing parameters on the surface of the processed work piece and degree of hardening have different influence, for different processed materials, the appropriate selection of rolling pressure, rolling speed, feed and other process parameters combination, can reduce the surface roughness, improve the degree of surface hardening of the work piece, to avoid the occurrence of surface plastic bulge, micro-crack and self-excitng vibrations occur. In the experiment of this paper, the work piece is a cylindrical part made of carbon structure steel, with a diameter of 30mm. The roller is designed as spherical, made of GCr15 bearing steel, the roller diameter of 6mm, the ultrasonic vibration frequency of the roller is 20kHz, the ultrasonic vibration amplitude is 20μm, using oil as a lubrication coolant.

Figure 4 shows the impact curve of rolling pressure on surface roughness, with feeds of 0.05mm/r, 0.11mm/r and 0.22mm/r, respectively. In the smaller rolling pressure range, i.e. in the range of 25-80N, the surface roughness value will show an overall downward trend with the increase of the rolling pressure. Due to the effect of ultrasonic vibration, the rolling effect can be obtained by a smaller rolling pressure. The original cutting marks on the work piece surface are squeezed and flat, and the surface quality is significantly improved.

Figure 5 is the photos of the surface of the ultrasonic rolling processing work piece at different rolling pressures at a swing line speed of 148m/min and a feed of 0.05mm/r. It can be seen that there is
a clear difference in the surface roughness of the test piece at the rolling pressure of 35N, 60N and 80N. With the gradual increase of rolling pressure, the surface finish is getting better and better, which is consistent with the change of surface roughness in Figure 4.

![Figure 5. Ultrasonic rolling processing work piece surfaces under different rolling pressures.](image)

If the rolling pressure is selected as 80N, the feed is selected to 0.05mm/r, the work piece swing line speed is 19m/min, 75m/min, 148m/min, ultrasonic rolling processing work piece surface is shown in Figure 6. The basic law is that the higher the speed, the smaller the surface roughness value, that is, the higher the improvement of surface quality. It can be seen that surface roughness decreases with the increase of the rolling speed and the surface quality improves with the increase of the rolling speed.

![Figure 6. Ultrasonic rolling workpiece surfaces at different rolling speeds.](image)

5. **Ultrasonic rolling processing improves the surface micro-hardness**

After ultrasonic rolling processing, the surface micro-hardness of the work piece is significantly improved, and the wear resistance and fatigue resistance of the work piece will be improved. The effect of rolling pressure and work piece swing line speed on the micro hardness of the surface of the ultrasonic rolling work piece is shown in Figure 7. With the increase of rolling pressure, the micro hardness of the work piece surface increases gradually. The selection of the appropriate rolling pressure can significantly increase the micro-hardness of the work piece surface and significantly reduce the surface roughness (see Figure 8(a)). However, the rolling pressure can’t be infinite increase, when the rolling pressure is too large, will make the surface quality of the work piece deterioration (see Figure 8(b)), and even in the surface of the work piece appear small cracks, the work piece fatigue strength will be greatly reduced. In addition, the optimum rolling pressure is also related to the diameter of the roller and the material of the work piece. When the roller diameter is large or the work piece hardness is small and the plasticity is large, the rolling pressure can be selected to be larger.
Figure 7. Relationship curve between rolling pressure and surface hardness at different speeds.

Figure 8. Differences on the surface of the work piece when the rolling pressure is moderate and the rolling pressure is too high.

It is important to use lubrication fluids such as oil with good performance during ultrasonic rolling. Reasonable use of lubrication fluid, with the role of reducing the temperature of the processing area, roller service life increased. Reasonable use of lubrication fluid, but also can make ultrasonic rolling processing work pieces to obtain good surface quality, to prevent micro-cracks on the surface.

6. Conclusion
In ultrasonic rolling processing, the use of a small rolling pressure can reduce the surface roughness of the work piece, surface quality and micro hardness can be improved, can effectively avoid plastic bulge and micro-cracking. The process effect is good. The selection of process parameters such as rolling speed, rolling pressure and feed can improve the surface performance of the work piece. During processing, the more fully lubricated, the better the rolling effect.

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