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Study on Warm Forging Prosess of 45 Steel Asymmetric Gear

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Abstract. Asymmetric gear has complex structure, so using plastic forming technology to process the gear has problems of large forming load, short die life, bad tooth filling, and so on. To solve these problems, this paper presents a radial warm extrusion process of asymmetric gear to reduce the forming load and improve the filling in the toothed corner portion. Using the new mold and No. 45 steel to conducting forming experiments under the optimal forming parameters: billet temperature is 800 ℃, mold temperature is 250 ℃, the forming speed is 30mm/s, and the friction coefficient is 0.15, we can obtain the complete asymmetric gear with better surface and tooth filling. Asymmetric gears' microstructure analysis and mechanical testing showed that the small grain evenly distributed in the region near the addendum circle with high strength; the area near the central portion of the gear had a coarse grain size, uneven distribution and low strength. Significant metal flow lines at the corner part of the gear indicated that a large number of late-forming metal flowed `into the tooth cavity filling the corner portion.

1. Introduction

Gear is a mechanical transmission component commonly used in the mechanical structure. It has been widely used in many areas of industrial production such as automotive, aerospace, marine, machine tools, engineering machinery, light industry machinery, metallurgical machinery and instruments[1-3]. The bearing capacity of the gear depends on its' pressure angle, the greater the pressure angle is, the higher the bending fatigue strength is. The tooth top of the gear comes to a point due to the increase of the pressure angle, which will lead to decrease of capacity of resistance to impact load. However asymmetric gear is a new type of gear which is designed for improving the bending strength and its characteristic is having two different pressure angle, corresponding to the two asymmetric involute. This kind of gear has many advantages such as small volume, light quality, large carrying capacity, etc. [4-7]

The gear processing methods are divided into machining and plastic forming. Gear machining has some defects, such as damage of metal flow line, resulting in a decline in gear strength, low material utilization rate, a considerable part of the billet is removed or becomes into an iron scrap in machining process. After machining the blank also need heat treatment to improve its mechanical properties. This procedure will increase the complexity of the process, and maybe affect the precision of gears. Using plastic forming process to produce gear can improve the utilization of raw materials and production efficiency, increase the mechanical properties of gears. As a consequence, exploring the plastic forming process of asymmetric gear has wide application prospects[8-12].

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This artical studies on precision forging process of 45 steel asymmetric gear, presents a radial warm extrusion process of asymmetric gear to reduce the forming load and improve the filling in the toothed corner portion

2. Experimental procedure

45 steel without quenching used as experimental blank with specifications of Φ32×20. Using four-column hydropress with pressure of 200 tons as forming equipment. Firstly, mould was preheated to 250 ℃ (about 2.5 h) and the mould surface was sprayed by graphite coating. Billet will be heated to 800 ℃ used by a induction heating equipment with water-cooled copper crucible, then quickly put the heated billet in a tooth profile extrusion die to forming. Subsequently, the microstructure and mechanical properties were characterized of forming specimen were investigated.

3. Results and discussion

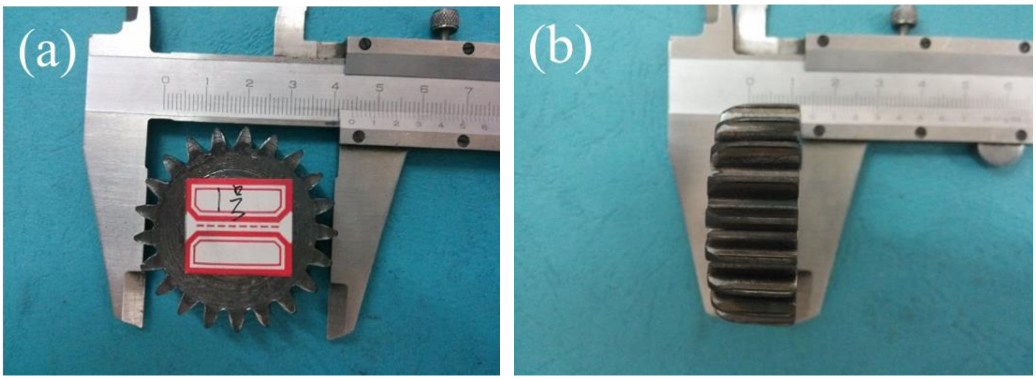

Figure 1. Digital image of the formed asymmetric gear

Digital image of formed asymmetric gear was shown in figure 1. From the image we can see that the top and bottom of gear's corner were partly filled completely, asymmetric tooth profile was obvious. The effect of overall forming was excellent in addition to the slightly uneven surface because of the mould structure. Excess metal in the rectangular shunt cavity could be seen from the side image, redundant rectangular columns were formed above the addendum circle. Excess metal flowed into the shunt cavity which is on the top is more, and flowed into the shunt cavity at the bottom of gear was smaller, relatively.

3.1 Microstructure of the formed asymmetric gear

Figure 2 shows the microstruture of metal flow line in different part. The direction of metal flow line could be found in the picture. From the figure 2(a) which is the part of asymmetric gear addendum circle, it can be seen that grains are pressed flat along the radial direction, which flow to the angle, and the flow lines on the top are also along the radial direction. That reveals that in the process of metal filling cavity, excess metal flow to shunt cavity, and the shunt cavity on the top is not completely filled by metal, it will make that there are still many free flow of metal at the end of forming, process which lead to reduce the forming force greatly. Figure 2(b) is the middle part of the involute, the metal flow line in this part is obvious than which in (a), direction is also radial. Image (c) shows the rounded part between dedendum circle and involute, the metal flow can be seen here is very clear, this is due to the violent impact between die and metal blank of which flow direction will be changed under the effect of die. Deformation of the metal in this part is more obvious, its mechanical properties will be different from the other part.Image (d) is near to the transition fillet, within the grain was flattened, but the direction is different due to that the metal in this part had upsetting deformation and the gear filling process at the same time. In the upsetting deformation, this part of the metal had a trend of circumferential flow due to the increase in billet diameter. In the filling process, the metal flow to the cavity part, which caused this part of the metal had a trend of the radial flow. All above makes the metal flow direction in this area was not unified. (e) and (f) belong to the inner part of the billet. The images reveal that the grain did not occur to extrusion deformation, and the metal flow was not obvious, this is because the two parts of metal's deformation is very small in the forming process of asymmetric gear, for another the metal flow is also lesser.

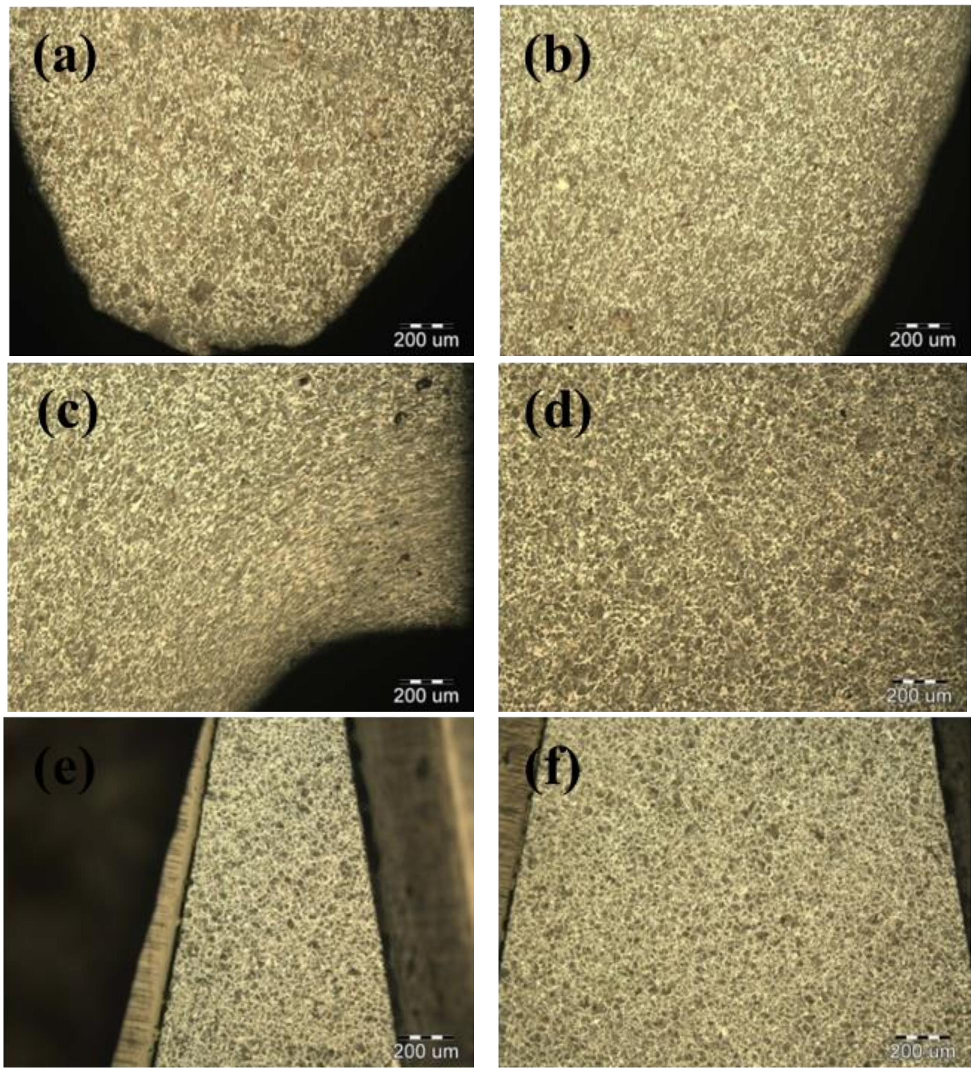

Figure 2. Microstruture of metel flow line in different part

Using higher-expansion microscopic analysis to observe grain size and distribution. Figure 3 shows the metallographic image of gear which was magnified 500 times. In terms of grain size, we can find that the grain size of (b) and (c) is relatively smaller than that of (a) and (d), and the grain size of (e) and (f) is the most massive. From the uniformity of the grain size distribution, (b) and (c) is the optimal, (a) and (d) is a bit poor, (e) and (f) is uneven. This reveals that in the process of radial extrusion of asymmetric gear, deformation in the part of rounded and involute tooth profile is larger, and its grain was isometrically extend along the radial under the action of external force. At the same time the structure became refinement and forming a fine organization, this deformation process of this part of metal will be accompanied by a large number of dislocation multiplication, which would make the deformation resistance of the metal increases, this part will be discussed in the next section.The metal in the area (a) mainly flowed belong radial under the action of terrace die because of the shunt cavity, which different from the process of (b) and (c). So the grains size in (a) is smaller than, but bigger than the (b) and (c). is There was no significant of metal flow deformation in region (e) and (f), therefore its grain was bulky, and distribution of grain was uneven.

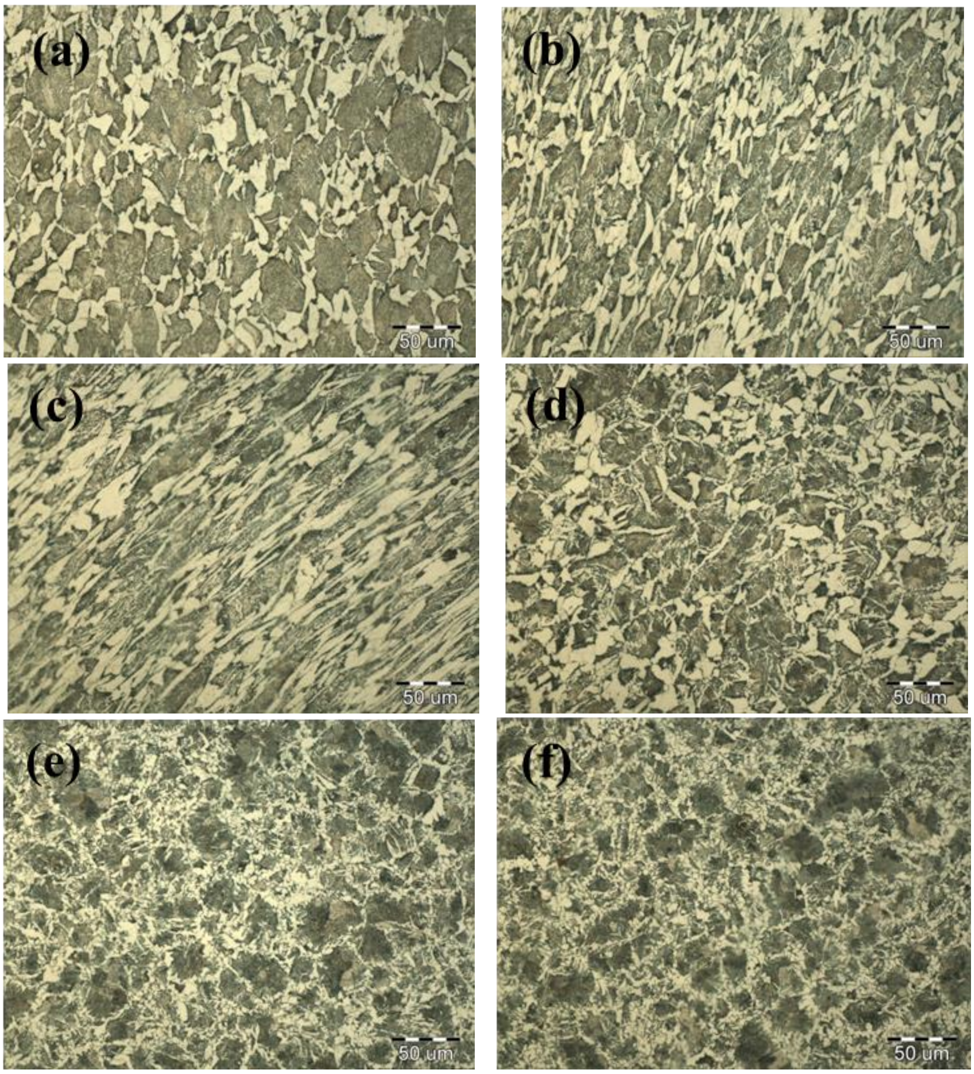

Figure 3. Microstruture of grain in different part

Observing the grain structure, we find that the organization of each area is pearlite grains, which is a mixture of ferrite and cementite organization in the warm forging experiments of asymmetric gear, there is no presence of the martensite structure. The warm forging temperature is 800℃, the austenitizing have occurred at this temperature, and the adoption of the cooling system is air cooling after forging, the cooling speed is less than the critical cooling rate, so the organization is pearlite.

3.2 Mechanical properties of the formed asymmetric gear

Table 1. The hardness in different region

	1st/HV	2st/HV	3st/HV	average /HV
region1	180.22	175.57	184.36	180.05
region2	172.13	164.04	168.84	168.34
region3	199.82	203.45	208.65	203.97
region4	148.79	151.84	145.93	148.85
region5	131.20	136.75	124.58	130.84
region6	125.54	120.21	131.53	125.76

Figure 4 shows the hardness in different region on the basis of Table 1. It can be obviously found that the hardness is higher in where the deformation of asymmetric gear forming is large in the process. Because the warm forging temperature is 800 ℃, above the recrystallization temperature of 45 steel, so a lot of original rough grains become fine uniform after recrystallization, combined with the structure refinement when the metal occurs to plastic deformation, and the proliferation of dislocation result in the increase in strength. The greater the deformation, the more obvious the strain hardening process , the higher the hardness.

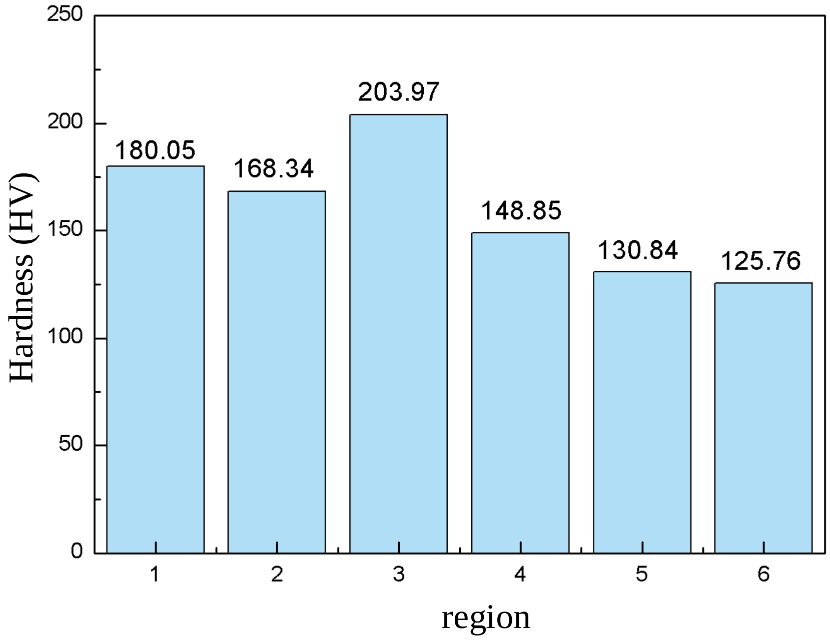

Figure 4. The hardness in different region

Table 2. The compression results in different region

	Yield Strength/MPa	Ultimate Strength /MPa	Compressive	Compressive Strain/%
Sample1	739.87	2757.49		71.30
Sample2	690.16	1857.36		60.03
Sample3	688.91	1307.61		39.80

There are some parts are not suitable for tensile experiment due to the smaller and irregular shape, so experiment test of the compression strength is adopted. We get sample 1, 2, 3 from the tooth part, middle part and tooth part of the gear, respectively. tooth part is the sample 1, the middle section is sample 2, tooth heart part for sample 3. Compression performance of three samples tested by electronic universal testing machine, the result is shown in figure 5. Table 2 is the compression results of the three samples.

Both figure 5 and table 2 illustrate the gear mechanical properties (compressive strength, ultimate compressive load and the ultimate compression strain) become poor from the top circle part to tooth heart gradually. The tooth shape parts compared with the tooth of the heart, of which the compressive strength increased by 7.40%, the ultimate compressive strength increased by 110.8% and the biggest compressive strain increased by 79.15%. Three samples' flow stress is not quite difference before happen to yield, but the flow stress of sample 2and 3 increases with the increase of deformation due to work hardening after yield, and sample 1 has long yield platform until its deformation reaches 43%.

The three samples' intensity has no significant difference, but the difference of plastic is larger caused by the microstructure. Grain of the sample 1 is fine and uniform distribution, deformation in more grain, strain in grain boundaries and internal is similar, so the deformation is uniform. Sample 2 and 3 have an uneven distribution of grain which is relatively bulky and its deformation is prone to stress concentration and fracture, so the plastic is poorer. Since all three samples are pearlitic structure without martensite structure, its yield strength is smaller.

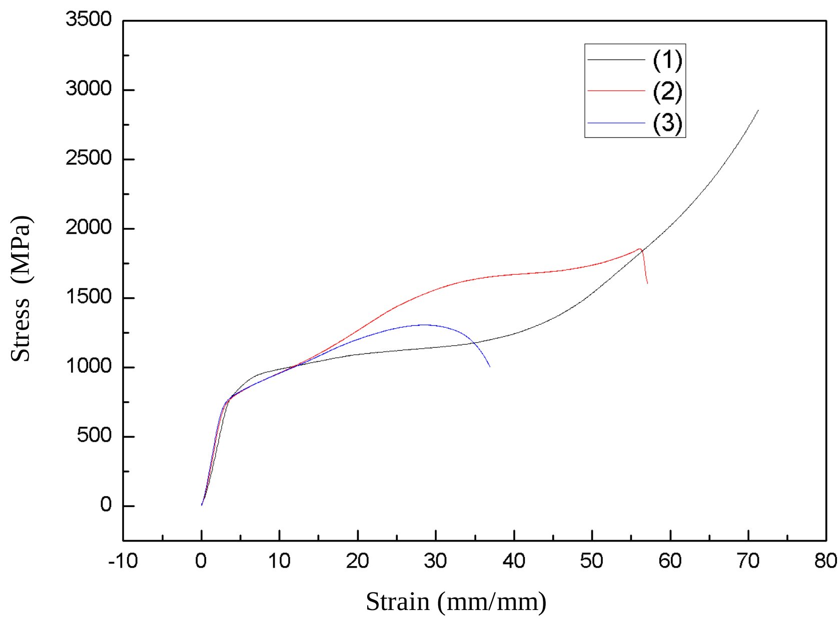

Figure 5. The hardness in different region

4. Conclusion

This paper presents a radial warm extrusion process of asymmetric gear to reduce the forming load and improve the filling in the toothed corner portion Asymmetric gears' microstructure analysis and mechanical testing showed that the small grain evenly distributed in the region near the addendum circle with high strength; the area near the central portion of the gear had a coarse grain size, uneven distribution and low strength. Significant metal flow lines at the corner part of the gear indicated that a large number of late-forming metal flowed `into the tooth cavity filling the corner portion.

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