Study on Recrystallization Organization of Workpiece about Processing Hole Using Friction Heat

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Abstract. The new technogical process is a kind of green mechanical processing without chip in this paper, the process can form relative deep hole in thin panel by friction heat between the drilling tool and workpiece, and it not only saves material, but also saves man-hours. In the paper, simulated analysis about the influence of different rotate speed and feed speed on the temperature field of forming hole of workpiece, and researched on the influence of processing parameters to recrystallization percent distribution and grain size of the around hole; Finally studied experimentally on the microstructure distribution by FEI Sirion and contrasted analysis the grain size around the hole of different location of test and simulation. The research results show that the simulation results agree well with the actual test results, and the appropriate process parameters are found to form hole under the conditions of this paper. The research results are useful for further optimization of the process in order to produce deep hole workpiece with ideal recrystalallization organization.

1. Introduction
The current machining process goal is to have the machining process with high efficiency, low consumption and high quality. In the modern manufacturing, hole is a very important part of spare parts. In the traditional processing of thin-wall hole machining, hole depth and thickness are equal, and not directly to machining thread of follow-up process. It is a major task to how to reduce resource consumption and reduce the environment pollution for the current manufacturing [1]. In this paper, the new technological process to form deep hole in relative thin panel by friction heat not only saves material, but also saves man-hours, and the workpiece has a good piece of assembly [2].

The process is a kind of green mechanical processing without chip. The process is similar to the extrusion process [3]. Due to the hole wall is got through the hot deformation of a material, so the metal flow line distribution is more reasonable, and the hole has good mechanical properties. Numerical simulation is a kind of effective methods to research sheet metal stamping and extrusion [4,5]. Currently, the main research contents are for drill friction heat production model, the influence of process parameters on the drilling and the blade geometry design [6,7], and the drill tool [8].

The important problem is studying on workpiece quality for the processing. The Performance of workpirce depends on the workpiece microstructure, and the hole is formed by friction heat, so a key problem of forming hole is about microstructure of forming area of the hole. The paper focused on the recrystallization organization of hole forming area.
2. Research Influence of Process Parameters on the Microstructure

2.1. Simulation Conditions
The test workpiece is 20 steel whose thickness is 4mm in this paper. The drilling tool materials is YG6X cemented carbide. The key parameters in simulation: environment temperature is 20°C, deformation temperature is 900–1200°C, drilling tool rotate speed is 1500–3500rpm, feed speed is 0.2–2mm/s, original grain size is 50µm, the friction factor is 0.2.

At first the two geometric models about workpiece and drilling tool are drawn with UG, and convert to STL format into the finite element simulation software Deform. Figure1 shows mesh work.

The rotation speed and feed speed of drill tool are important influence factors on the hole forming process and structure property of workpiece, therefore, the following analysis is made in this paper in order to get the optimum technological parameters in the process of machining deep hole on sheet.

![Figure 1. Meshed schematic of two objects](image)

2.2. Influence of Rotating Speed on the Microstructure
In the process of processing deep hole in sheet, different rotating speed will produce different frictional heat when the feeding speed of drilling tool is constant. Deformation temperature is important to influence workpiece forming effect and grain size and grain distribution after deformation, the study is useful because the microstructure of the hole decides performance of workpiece.

Figure 2 shows sheet temperature field distribution with different rotational speed when the feed rate of drilling tool is 0.6 mm/s.

![Figure 2. Distribution of temperature field with different speed cases](image)

(a) n=1500 rpm  (b) n=2500 rpm  (c) n=3500 rpm

Figure 2 shows that deformation zone temperature of sheet also increase gradually with the increase of drilling tool rotation speed when the tool feed rate is constant. The highest temperature of
deformation area corresponding to three kinds of drilling rate are 778°C, 1140°C and 1230°C respectively. The highest temperature of figure 2(a) and figure 2(c) are beyond the scope of reasonable hot working temperature. Figure 2 shows that shaping effect is not the same under different conditions, the length of the hole wall deformation area also increased with the increase of the maximum temperature deformation area, the reason is that metal plasticity increases with the increase of temperature, the movement of metal atoms under the precondition of the same feed speed, and plastic enhance, metal break after longer time, the length of the hole wall deformation area increases.

Figure 3 is percentage distribution of dynamic recrystallization of deformation area under different rotational speed when feed rate of drilling tool is 0.6 mm/s.

Different deformation zone temperature range agrees with the percentage of dynamic recrystallization and distribution according to figure 2 and figure 3. When rotational speed of drilling tool is 1500rpm, and the temperature ranges is between 125°C and 778°C, a lot of deformation area temperature can’t reach appropriate recrystallization temperature of 20 steel, therefore, the recrystallization happened in the wall of hole area is less, the percentage of dynamic recrystallization is about 0.05. When rotational speed of drilling tool is 2500rpm or 3500 rpm, the simulation results show that both dynamic recrystallization percent peak of deformation area is 1, but distribution area is different, compared to dynamic recrystallization of regional distribution of the former is more reasonable than latter. The highest temperature of latter reached 1230°C which is beyond to the reasonable processing temperature range, and the grains of forming area become big, then the workpiece makes some defects such as superheat, overburning, and decarburization.

Drill speed of too high or too low will reduces the deformation of organizational performance of forming hole area. When the drilling tool rate is too low, the deformation temperature of forming hole area can not reach the minimum temperature of recrystallization temperature, and not for dynamic softening, then microstructure not improve; when drilling rate is too high, the temperature of the deformation zone temperature exceeds the reasonable range, grains of workpiece forming area become big, and workpiece performance deteriorate. So its reasonable speed of the drilling tool is about 2500rpm in this paper.

2.3. Influence of Feed Speed on the Microstructure
In the process to form deep hole in sheet, the feed speed is an important influence factor also for the final shape effect and the performance of important parameters of the product. The feed speed is not only related to the final deformation zone temperature, but also limits the time to happen dynamic recrystallization in workpiece material. It is very necessary to study the effects of the change of the feed speed.

Figure 4 is sheet temperature field distribution with different feed rate when the rotational speed of drilling tool is 2500rpm. Feed speed can also make very different deformation zone temperature shown as figure 4.
Under the condition of the same rotate speed, feed speed of drilling tool is more slow and more long contact time between the drilling tool and the sheet, and the friction heat is more, though time of heat exchange from the sheet to outside air in the process is longer also, the exchange heat is much less than frictional heat, then lead to higher temperature of deformation zone. In addition, because the exchange heat time is long, temperature distribution in the workpiece is relatively even; the contact time of drilling tool and sheet decreases, temperature of workpiece is reduced, and the around temperature of workpiece is lower because of short exchange heat time and high temperature of the centre of forming area.

Figure 5 is percentage distribution of dynamic recrystallization of deformation area with different feed rate of drilling tool when rotational speed is constant.

Different feed speeds can cause a lot of difference of temperature of the deformation area, and the deformation of dynamic recrystallization fraction and distribution are obviously different shown as figure 5, so it is similar to the impact of rotate speed of drilling tool to temperature of forming area. In addition, the deformation speed has another influence on the recrystallization distribution of workpiece material, when the feed speed is too fast, the inside of the material grain failed to fully dynamic recrystallization occurs, the recrystallization can't overcome work hardening in a timely manner, which causes high hardness and brittleness material of deformation area, and adverse effect especially for subsequent thread processing. Sometime the workpiece material may break more early, and the depth of forming hole is not ideal.

In a word, reasonable process parameters can achieve ideal appearance size and improve organizational performance. In the paper, relative reasonable process parameters are 2500rpm of rotate speed and 0.6mm/s of feed speed by finite element software Deform-3D.

3. Simulation Results and Experimental Analysis
Figure 6 is profile of temperature field of cutting plane. The temperature variation range after workpiece deformation is between 223°C and 1140°C shown as figure 6 according to the analysis of cloud picture, the temperature of wall of hole is highest in the picture, which is due to a lot of heat
generated in the friction directly when the drilling tool touches sheet. Due to the effect of thermal diffusion of the workpiece itself, the heat of workpiece center diffuses to out the deformation area and results in the decrease of the temperature gradient distribution, uniform, the temperature of the temperature of panel edges decreases to around 220°C which is beyond to the lowest temperature to occur recrystallization.

Figure 7 is percentage distribution of dynamic recrystallization of the symmetry plane. The comparative analysis between figure 6 and figure 7 can conclude that the dynamic recrystallization percentage distribution corresponds with the results of the temperature field distribution. The highest temperature is in the center of whole wall where the deformation is largest in all deformation area, so the dynamic recrystallization of the area is sufficient to happen, and the microstructure is also refined. The temperature of edge of whole wall decreases, but it is still higher than the temperature of recrystallization temperature, it similar to occur the part of the dynamic recrystallization. The temperature of area outside of deformation section is low so that the deformation quantity is little or no deformation, therefore, dynamic recrystallization can’t occur.

The grain size and distribution are the direct factors influencing the material performance. Some typical regional feature points in symmetry plane after the simulation on figure 8 are marked and the grains size at these feature points are measured and compared with the experiment results.

![Figure 6. Temperature field of symmetry plane](image1.png)

![Figure 7. Distribution of dynamic recrystallization](image2.png)
The test workpiece material: 20 steel, sheet thickness is 4mm. The rotation speed and feed speed of drilling tool are 2500 rpm and 0.6 mm/s respectively. The sizes of grains of representative area in the cross section deformation area are measured by FEI Sirion scanning electron microscope, and the distribution of grain size and changes may be observed.

Figure 9 shows distribution diagram of microstructure of some representative area on the cutting plane of test workpiece by FEI sirion scanning electron microscope. In figure 9, grains of deformation area are smaller than the original grains, which show producing dynamic recrystallization. The grain sizes of points P1, P2 are between 12µm and 16µm. The grain size of points P3 is about 25µm. The grain size of points P4 is about 34µm. The grain size of points P5 is about 50µm as same as the original grain size because of almost no recrystallization P5 point on the edge of the billet. Therefore, the deformation degree of different parts is different, percentage of dynamic recrystallization is different also, and the grain size is small where recrystallization is full of regional, on the contrary, dynamic recrystallization in the distal of components can’t occur, so the grain size is as big as original grain size.

Figure 8. The study points

Figure 9. Distribution diagram of microstructure patterns on cutting plane
All point of the simulation of the grain size data compared with the estimated value of each point after the experiment shown as figure 10. There is a certain deviation shown as figure 10, because the boundary conditions in the simulation process by simulation software are not the same as the actual operation, and although the process of heat conduction and thermal diffusion may be considered, recrystallization mathematical model can not calculate very accurately the deformation in the process of grain size of dynamic recrystallization and grain growth. The error of two groups of data is not big. The research results can prove the validity of the simulation.

Figure 11 shows actual cutting plane figure. Two image contrast can be seen that the simulation results are in conformity with the actual dimension, the simulation effect is feasible.

![Data comparison between simulation and experimental](image1)

![The workpiece section](image2)

4. Conclusions
When the other conditions are constant, the rotation speed of drilling tool is too small to get enough high deformation zone temperature and make dynamic recrystallization forming deep hole in sheet, and forming effect is low. When drill speed is high, the deformation zone temperature is enough high to cause overheating phenomenon and get the coarse grains; the feed speed of drilling tool is too fast to get enough time to make material grain to happen adequately dynamic recrystallization forming deep hole in sheet, so the recrystallization cannot overcome work hardening in a timely manner; feed speed is too slow, the contact time between drilling tool and the material deformation area is too long also, then to generate enough heat also to influence grain refinement.

Based on the research of this paper, the suitable condition of process parameters to get recrystallization organization is: rotation speed is 2500 rpm, feed speed is 0.6 mm/s.

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