Research on Drilling Force Model of KFRP

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Abstract. Kevlar fiber reinforce polymer (KFRP) is abroad applied in military weapon with excellence performance, but it is difficult-cutting-material. For improving its cutting efficiency, drilling parameter optimize model of KFRP was researched. Based on the cutting test data, the optimize model of KFRP was obtained by linearity regression method. The comparison result of experiment value and simulation value indicated that MA.FORD unconventionality drilling tool was suit for KFRP, and had the advantages at high speed cutting; SUPERLERTOOLS conventionality drilling tool was not suit for KFRP. In addition, the main cutting force reduced with cutting speed and had little change with feed speed for MA.FORD tool.

1. Introduction
Kevlar fiber reinforced composite (KFRP) has the characteristics of high strength, low density, high toughness and not easy to melt. It has been widely used in weapon equipment for its excellent performance[1]. As a lightweight material, KFRP has excellent ballistic performance and significantly improves the comprehensive protection of armored vehicles. In the coupling of Kevlar composite components, it is usually necessary to process a large number of holes. Due to the high toughness and tensile strength of the Kevlar fiber, the tool wear is severe and the processing efficiency is low, which is a difficult material to be processed. At the same time, processing defects such as material delamination, drawing, napping, material bulging, hole surface roughness, and dimensional shrinkage are easily caused, resulting in material damage around the hole, and the processing quality is difficult to control[2-5]. Nanjing University of Science and Technology has done a lot of work in the processing of KFRP[6-8].

In this paper, the cutting force model of Kevlar fiber reinforced composites was studied by cutting force test. The KFRP drilling force model was constructed by linear regression method through single factor experiment, which provided a reference for the optimization of KFRP cutting parameters.

2. Experiment program
2.1. Workpiece and tool
The workpiece material was Kevlar fiber reinforced composite kevlar–49. Two different types of carbide drills were selected, including conventional carbide tool and unconventional carbide tool: SUPERLORTOOLS D644080 (Figure 1), MA.FORD 20731500 (Figure 2). In contrast, the MA.FORD unconventional tool has two sharp tips, while the conventional SUPERLORTOOLS tool has two cutting edges. The diameters of the two drills both are 8 mm.
Table 1. Test tools

| Number | Manufacturer   | Tool material    | Tool type      | Diameter (mm) | Specification number |
|--------|----------------|------------------|----------------|---------------|---------------------|
| 1      | SUPERLORTOOLS  | Cemented carbide | Overall drill  | 8             | D644080             |
| 2      | MA.FORD        | Cemented carbide | Overall drill  | 8             | 20731500            |

Figure 1. SUPERLORTOOLS conventional drill

Figure 2. MA.FORD unconventional drill

2.2. Experiment program

In order to reduce the number of tests, increase the information amount of each test point data, and enhance the accuracy of the prediction model, the single-factor drilling test was carried out at a given feed rate and speed. The selection range of test parameters is shown in Table 2.

Table 2. Cutting parameters

| Speed \(v_c\) (m/min) | 100.5 | 113.2 | 125.6 | 138.2 | 150.7 |
|-----------------------|-------|-------|-------|-------|-------|
| Feed \(f_z\) (mm/z)   | 0.02  | 0.04  | 0.06  | 0.08  | 0.1   |

Figure 3. The force platform schematic

The test was carried out on the Mikron UCP800 machine. The maximum speed is 20000 rpm, the power is 30 kW, and the maximum feed speed is 20 m/min. The Kistler 9265B dynamic force gauge is used to measure the drilling force, and the charge amplifier is the Kistler 5017A. The force test platform is shown in Figure 3.
3. Results and analysis

3.1. Drilling force empirical formula

The Kevlar's force empirical formula was obtained by linear regression using single factor test. The force-cutting speed relationship was fitted. According to the cutting theory, the three-way cutting force and the cutting speed are both power-finger relations, \( \log F \) and \( \log V_c \) are linear, so the relationship can be determined using linear regression.

The empirical formulas for the three-way cutting force of MA.FORD tool obtained were:

\[
F_x = 26861 \cdot V_c^{-1.787} \cdot f_z^{-0.437} \\
F_y = 5.2 \cdot V_c^{-0.135} \cdot f_z^{0.586} \\
F_z = 301 \cdot V_c^{-0.414} \cdot f_z^{0.063}
\]

(1) - (3)

The empirical formulas for the three-way cutting force of SUPERLERTOOLS tool obtained were:

\[
F_x = 95.4 \cdot V_c^{-0.606} \cdot f_z^{0.302} \\
F_y = 62 \cdot V_c^{-0.424} \cdot f_z^{0.199} \\
F_z = 87 \cdot V_c^{-0.489} \cdot f_z^{0.547}
\]

(4) - (6)

3.2. Cutting force analysis of MA.FORD

The fitting force values in the corresponding cutting parameters were obtained according to the above formulas (1) - (3). Figure 4 and Figure 5 show the relationship between the test values and fitting values of the cutting force when the MA.FORD tool drilled KFRP. It could be seen from the figure that the error between the test value and the fitted value was small, and the empirical formula obtained by the test could well reflect the relationship between the cutting force and the cutting speed, feed rate. When the MA.FORD tool drilled KFRP, \( F_z \) is the axial force which is the main cutting force. The main cutting force tended to decrease as the cutting speed increased, and changed little as the feed rate increased. In addition, the cutting force was stable when the MA.FORD tool drilled KFRP. It could be seen that this tool was suitable for processing KFRP and should be processed at high cutting speed.

3.3. Cutting force analysis of SUPERLERTOOLS

The fitting force values in the corresponding cutting parameters were obtained according to the above formulas (4) - (6). Figure 6 and Figure 7 show the relationship between the test values and fitting values of the cutting force when the SUPERLERTOOLS tool drilled KFRP. It could be seen from the
figure that the error between the test value and the fitted value was large, and the cutting force fluctuated greatly, which was difficult to match the actual value. The main reason was that the cutting edge of the tool was not sharp enough. Although it could be processed, it was difficult to machine. Therefore, the SUPERLERTOOLS tool was not suitable for KFRP.

4. Conclusion

The drilling force models of the two tools drilling KFRP were fitted by linear regression method through single factor experiment, and the relationship between cutting force and cutting speed, feed rate was obtained. The main conclusions are as follows:

- When MA.FORD unconventional tool drills KFRP, the main cutting force tends to decrease as the cutting speed increases, and change little as the feed rate increases;
- The MA.FORD unconventional tool is suitable for drilling KFRP and more advantageous at high cutting speed;
- The SUPERLERTOOLS conventional tool is not suitable for drilling KFRP.

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