The method of finishing the inside of a minute hole

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1. Introduction
In recent years, various technologies for improving fuel consumption are developed in an engine system. Nozzles that supply fuel in those technologies play an important role. From now on, it is expected as diameter of the nozzle become small in order to realize high pressure in fuel injection system. In case of processing hole down to 0.2mm, a drilling process is generally used. The flow of the fuel in a nozzle depends on smoothness of the hole inside. Now, the polishing method corresponding to such the minute hole is not developed. The purpose of this research is improving the surface roughness of inside of the hole after the drilling process.

2. Electrolytic polishing
There are some ways for improving the surface roughness of the hole inside. For example fixed abrasive method or loose abrasive method is used. However these methods need tool rigidity, it is hard to respond to a small hole. Besides these are not suitable for polishing of hard material for nozzles. We adopted the electrolytic polishing method without necessity of considering the rigidity. It is easy to apply the process to high hardness alloy used for the high-pressure fuel injection technology. It is also suitable for finishing of a slanting hole.

3. Experimental procedure
Setup of experiments is shown in Fig.1. We smoothed side surfaces of the workpiece of stainless steel by grinding. Two smooth surfaces was stuck together by vice. We drilled the hole along the border of two surfaces in order to evaluate the inside wall easily. Electrolytic polishing (EP) was performed, after evaluating a hole inside and making the samples stuck together again. Power supply for EP is done by direct-current power supply equipment, which is used for constant current mode. Both scanning electron microscope (SEM) and stylus method surface profiling machine were used for evaluation.
4. Effect of electrolysis products
1) The flow of electrolysis liquid
First, in order to investigate the characteristic of fundamental electrolysis polish, the electrode was soaked in electrolysis liquid and the hole inside was polished. Fig.2 is a SEM image of the polished hole of 0.5mm diameter. Electrolysis liquid evaporated with heat, and the electrolysis products adhered to the inner wall. As a result it did not become the good surface. Thus we made the micro tube pump system to inhale the electrolytic liquid. Experimental conditions are shown in Table 1. In fig.3, both the surface of 100 milliamperes current supply and that of 200mA are better than fig.2. However, there is a slight difference between them. In 200mA, getting electrolysis products blocked with the hole inside, the surface turned into a spots polishing, and on the contrary it was not well polished in 100mA. We think the balance of the current of electricity and the amount of inhalation is required in order to acquire a good surface.

2) Rubbing action
As mentioned above electrolysis product prevents the surface from improvement in the surface roughness. Thus we tried to introduce a rubbing action during electrolytic process in order to remove the electrolysis generation compulsorily. We designed and tried various type of the electrode for working a rubbing action well. We tried what wound around the copper wire, thread, sponge, and the resin with slit (Fig.4). Most excellent electrode was resin by factors, such as durability.

5. Process parameters
1) Current
In electrolysis polishing, the electric current is the important element. So we investigated influence of the electric current value. Experimental condition is shown in Table 2. The results are shown in Fig.5 and 6. If the surface coarseness before and after polishing is compared, surface roughness became the best on 200mA by 100mA. We found existence of an optimum electric current value.

Table 2. Electrolysis polish conditions

<table>
<thead>
<tr>
<th>Current (mA)</th>
<th>Electrolyte solution</th>
<th>Concentration (wt%)</th>
<th>Voltage (V)</th>
<th>Polishing time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>NaNO₃</td>
<td>20</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300</td>
<td></td>
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</tbody>
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![Fig.5 The minute hole before polishing (a) and the minute hole after polishing (b)](image)

![Fig.6 Comparison of the cross-sectional form polishing before and after polishing](image)

2) The electrode rotation speed
In order to investigate influence of the electrode rotations speed, the experiments by 1000, 4000 and 7000rpm were done. Results are shown in fig.7. In 1000rpm, the electrolysis action is so
strong that the form has deteriorated. Especially the diameter at the inlet increases remarkably. Among them the best result is obtained in 4000rpm. In 7000rpm, the amount of polishing is small. Since the rotation speed is too fast we suggest that an electrolysis action does not work well.

6. Conclusions
1) We proposed the new polishing method of a minute hole inside by electrolysis polish.
2) Electrolysis liquid needed to be pouring compulsorily in order to prevent electrolysis products from adhering on the inside of a hole.
3) In order to remove electrolysis products positively, it is necessary to add a rubbing action by the electrode during the electrolytic polishing process.
4) We were able to acquire the better surface by the electrolytic polishing process using the newly developed electrode with a spacer.
5) There are optimum values on rotation speed of the electrode or on the current value of the current supply.

Fig. 7 Comparison of the cross-sectional form polishing before and after polishing

(a) 1000rpm

(b) 4000rpm

(c) 7000rpm