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A STUDY OF THE MACHINING METHOD OF INCONEL 625

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ABSTRACT

As we all know that automatic driving and electric car technology has been very much used in the world nowadays & India is also a part of that. However, the production of clean diesel engines in India & other countries like Europe is a challenge. A turbocharger is used in clean diesel engines, and as the parts materials, nickel-base superalloys are used. The machining of these materials is very difficult and as the finishing process grinding is used until now. So, the shortening of the cycle time & the reduction of the cost is another big problem. In this experiment valve, stem machining investigates experimentally the possibility of the substitution from conventional centreless grinding to external turning. The result of this experiment was that the surface integrity was able to be obtained by external turning with the CNC lathe within the range of customer demand. The opposed twine spindle CNC lathe used in this study was able to lead to success in the shortening of the machining time, the cycle time, and the reduction of the cost too.

Keywords: Turning, Surface Integrity, Inconel 625, Tool Wear, Shortening Of Cycle Time, Reduction Of Cost.

I. INTRODUCTION

The low-emission vehicles, like electric vehicles, diesel hybrid vehicles, fuel cell vehicles, and super clean diesel vehicles have been developed by the automotive industries nowadays, & the aim behind this is to conserve environmental regulation measures. Exhaust gas recirculation (EGR) is present in super clean diesel engines in a large amount as compared with the gasoline engine to reduce nitrogen oxide. This EGR reduces the temperature and the amount of nitrogen oxide in the combustion chamber. The EGR also causes the amount of oxygen to reduce in the intake passage due to this the high power requires the supercharging system. That's why the adaption and high performance of the turbocharger have been promoted. The parts made of nickel-base superalloy are used because the temperature of the exhaust gas is so high & nickel-base superalloys have high-temperature strength metals. These nickel-base superalloys are difficult-to-cut materials, and many studies on them have been carried out till now. For superior surface integrity, these turbocharger parts require precision machining. In this paper, Inconel 625 was used, and the workpiece was machined in the same size as the actual automotive parts. Tool wear & the effect of the cutting fluids and cutting conditions on the surface integrity were investigated, cost performance, and considering the global environment. This experiment aimed to improve the machining process method, the reduction of the cost, and considering shortening the cycle time.

II. EXPERIMENTAL

A. Workpiece: The valve stem of the Westgate-type turbocharger was used as the workpiece, in this experiment. It can keep its performance at the high exhaust gas temperature which amounts to 950°C approx. because its material is Inconel 625 which is the cast type nickel-base superalloy. The nominal compositions, the physical properties, and the mechanical properties of Inconel 625, respectively are shown in tables I, II, and III.

B. Conditions of Experiment: A rigid high-power lathe model “SPINNER.COM: COMPACT CNC TURNING CENTRE” was used in this experiment. The external turning was applied to the Inconel 625 test bar with 8.12mm in external diameter and 68.02 mm in length, which was used as the valve stem of the turbocharger by using the PVD coating positive throwaway inserts under the cutting conditions shown in Table IV. The part in the cantilever state from the lathe chuck was 35 mm as shown in Figure 1. The workpiece is customized to 7 mm in external diameter and 66 mm in length as a product. The rake angle was increased up to 18- degrees to reduce cutting resistance. It was found that the size error decreases, but because the wedge angle of the tool decreases, the tool life may shorten. There were three types of cutting fluids were used: 1. synthetic soluble as sample A, 2. an emulsion including a sulfur-type extreme pressure additive as sample B, and 3. a synthetic emulsion including a sulfur-type extreme pressure additive as sample C. The feature is shown in Table V. Each of the types was diluted 10 times, as a cutting fluid. The cutting fluid was added speed to the cutting point at the rate of 10 L/min with the external nozzle.

TABLE 1. NOMINAL CHEMICAL COMPOSITION OF INCONEL 625

Ni	Cr	Mo	Fe	Nb + Ta	Co	Mn	Al
58 - 71%	21 - 23%	8 - 10 %	5 %	3.2 - 3.8 %	1% max.	0.5% max.	0.4% max.

TABLE 2. PHYSICAL PROPERTIES OF INCONEL 625

Density	8.44 g/cm^3
Melting temperature	2462°F(1350°C)
Curie Point	-319°F(195°C)
Poisson's Ratio (at room temperature)	0.278
Shear Modulus (at room temperature)	81.4 GPa
Thermal Conductivity (at room temperature)	9.8 W/m*°C
Electrical Resistivity (at room temperature)	129 μΩ*cm

TABLE 3. MECHANICAL PROPERTIES OF INCONEL 625

Temperature	Yield Strength (0.20% Offset)		Tensile Strength		Elongation (%)
	Ksi	MPa	Ksi	MPa	
Room temp	69.5	479.2	140	1276	54
1598°F (870°C)	76.7	528.8	144	1034	34

TABLE 4. CONDITIONS OF CUTTING

Diameter, D (mm)	φ8.12
Rake angle, γ (deg.)	18
Corner radius, rε (mm)	0.2
Depth of cut, a (mm)	0.1
Cutting speed, V (m/min)	30
Feed rate, f (mm/rev)	0.01
Cutting length, L (m)	50, 100, 150, 200, 300

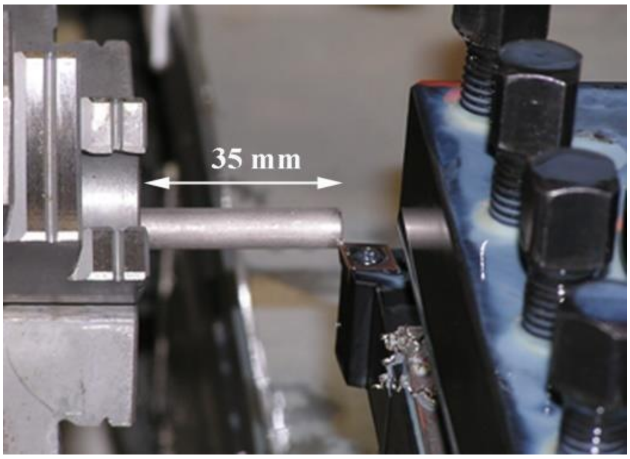

Figure 1. Experiment setup

After machining, the arithmetic average roughness Ra in the direction of the tool feed motion was measured with the surface roughness measuring instrument by stylus method at the position at which the circumference was divided equally into three. Furthermore, size error, roundness, and cylindricity were measured with the coordinate measuring machine. Changing the cutting length up to 300m, the surface integrity and tool wear was investigated.

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TABLE 5. CUTTING FLUIDS

Cutting fluids	Sample A	Sample B	Sample C
Type	Synthetic soluble	Emulsion	Synthetic emulsion
Density (g/cm3(15°C))	0.98	0.938	1.012
Surface tension (mN/m(25°C))	32.9	34	25.2
S (Sulfur)	-	○	○
P (Phosphorus)	-	-	-
B (Boron)	-	-	-
pH	9.3	9.7	9.87

III. RESULTS AND DISCUSSION

The effects of the cutting conditions on the arithmetic average roughness Ra are shown in fig. 2. Ra < 1.6 µm is the range of the customer demand. The larger the cutting length L is, the worse Ra becomes, and that Ra settled within 1 µm even when the cutting length L was 300 m, found from this figure. The synthetic emulsion of sample C was somewhat excellent for the effect of the cutting fluids. In addition to this, the adhesion area cannot be confirmed on the cutting edge after machining in the case of sample C, it seems to be superior in lubricity. It is to be considered that the surface of the work material performed efficiently when the tip was wet near the cutting edge, because of the smallest surface tension of sample C in all the cutting fluids used this time. The synthetic soluble in sample A obtained the same as the sample C. The synthetic solubility of sample A had a bigger surface tension than that of sample C, but its Ra was a little better than that of sample C. The value at room temperature indicates by the surface tension in table IV. Therefore, at a high temperature, the surface tension value may be changed. The effects of the cutting conditions on the size error are shown in figure 3. It reflects the difference in diameter between the workpiece measured by the end retainer setting with the CNC lathe after machining and that measured before machining. If the cutting length L increases, the size error becomes greater, like the previous result of the surface roughness. Due to the greater rake angle, this size error became smaller than the previous study's data. When the cutting edge of the tool is worn out as the cutting length increases, the cutting resistance increases gradually. The workpiece was easy to bend because the workpiece was held and machined in the cantilever style. The synthetic emulsion and the synthetic soluble enable the size error to keep below 50 µm at the cutting length L = 300 m, while the size error by using the emulsion is over 100 µm at the cutting length L = 300 m. The both-end support style should be used instead of the cantilever style because it is difficult to increase the rake angle. However, the lathe which can fix a workpiece well should be used, so that the workpiece is under 10 mm in diameter and its aspect ratio is over 9.

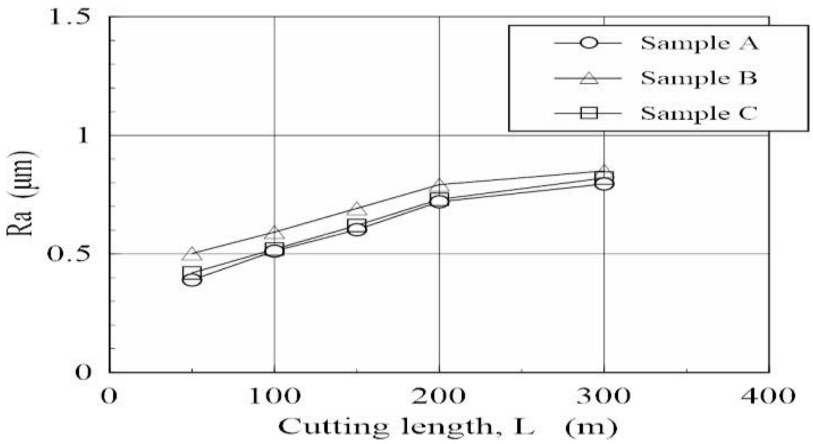

Figure 2. Effects of cutting conditions on Ra

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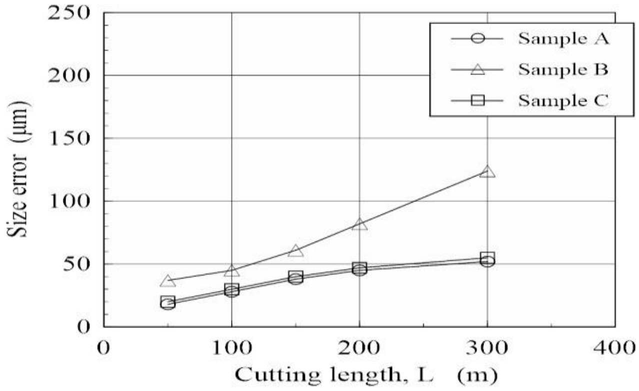

Figure 3. Cutting condition's effects on size error

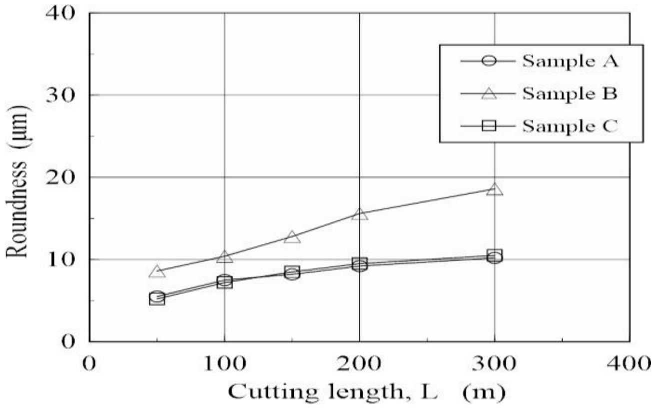

Figure 4. Effects of cutting conditions on roundness.

The effects of the cutting conditions on the roundness, shown in figure 4. It is found that the more the roundness increases if the more the cutting length L increases. In the case of the roundness, the synthetic emulsion and the synthetic soluble are more effective for the roundness than the conventional emulsion, too. the synthetic soluble and the synthetic emulsion enable the roundness to keep below 10 μm at the cutting length L = 300 m.

The effects of the cutting conditions on the cylindricity are shown in figure 5. In this case, it is also found that the more the cylindricity increases if the cutting length L increases. The synthetic emulsion and the synthetic soluble are more effective in the cylindricity than the conventional emulsion for the cutting fluid. All the fluids enabled the cylindricity to keep below 40 μm at the cutting length L = 300 m because the rake angle was greater this time.

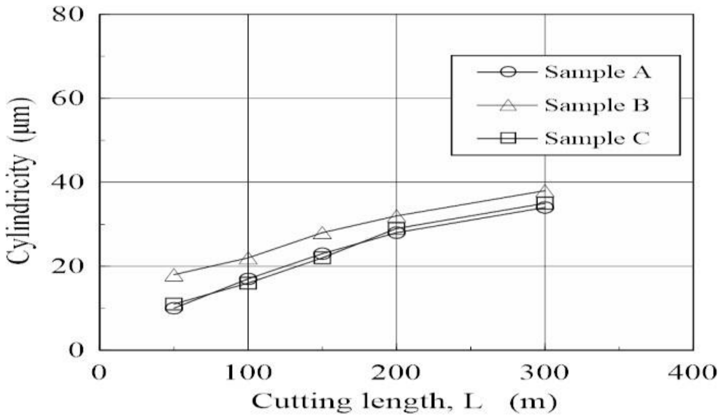

Figure 5. Effects of cutting conditions on cylindricity.

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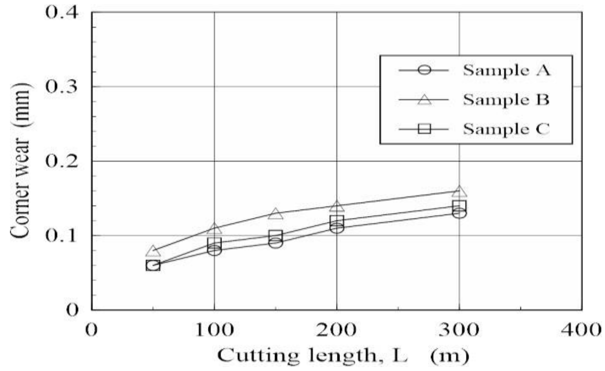

Figure 6. Cutting condition's effects on tool wear.

These results turned worse when the cutting length became 300 m. It is considered that tool wear influenced this. When the cutting edge of the tool is worn out as the cutting length increases, the cutting resistance increases gradually. Since the force with which the tool pushed the workpiece in the perpendicular direction to the rotation center increased due to the deformation of the workpiece held with the cantilever during machining, it is possible that the size error, etc. got worse.

The effects of the cutting conditions on the tool wear are shown in figure 6. The crater wear, flank wear, notch wear, and corner wear which was formed near the tool corner were observed this time for the tool wear. The width of the corner wear was measured because the corner wear was the largest for all. Also, it is found that the more the cutting length L increases, the more the tool wear increases. The rise of the cutting heat and the cutting resistance was controlled due to the large angle this time. Therefore, in all cutting fluids, the tool wear was able to be controlled below 0.2 mm at L = 300 m. The size error and the roundness were larger than in the case of other fluids whenever the cutting length was 300 m in the case of the conventional emulsion. The tool wear accelerated, and the characteristics of the cutting fluids in the state in which the cutting heat and the cutting resistance increased are likely to affect the surface integrity.

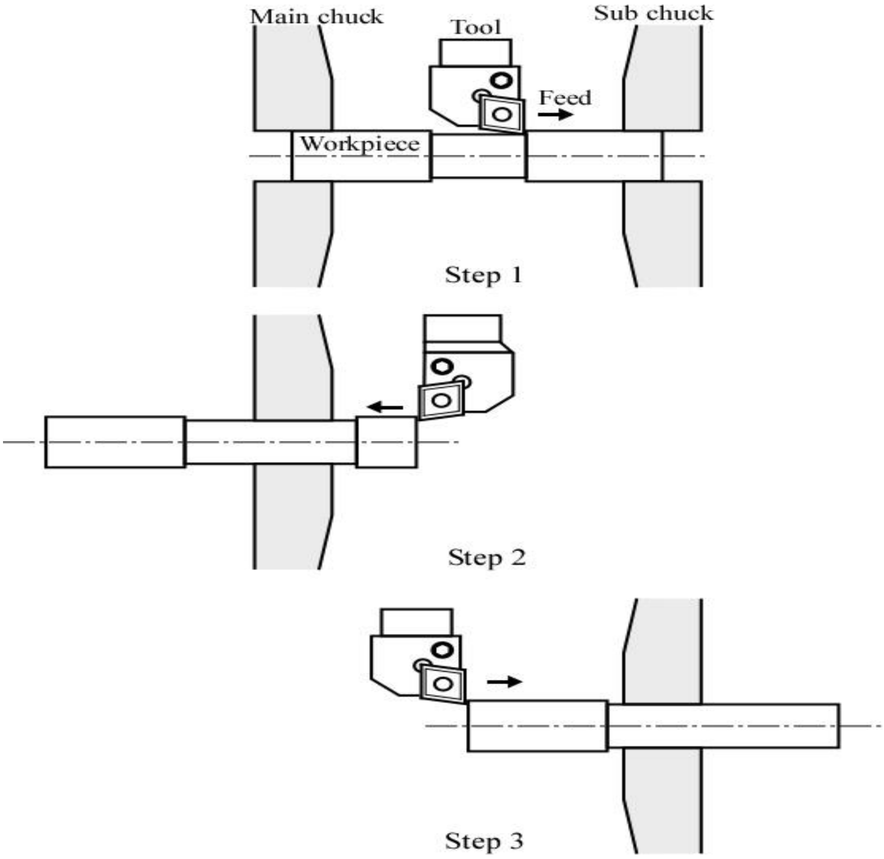

Figure 7. Machining process which was devised firstly.

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The experiment was performed to improve the production capacity, including the shortening of the cycle time or machining time and the reduction of the cost for the valve stem processing of the turbocharger parts. Till now, centreless grinding has been used to finish that product. The automation of machining which includes the shape measurement from roughing to finishing of this stem was investigated in the previous study. The automatic conveyance of the workpiece, the workpiece origin seeks, dimensional measurement, tool length compensation, and machining were carried out by a series of program operations. Renishaw touch probe OMP40-2 which was attached to the main and sub-tool post was used for dimensional measurement. Even if the rake angle is large, there was a limit to the restraint of the size error for the cantilever holding style in the previous study, but it is considered that the problem of the size error is solved by using the small diameter rod of the large aspect ratio by twin spindle methods in the both-end supporting style. Furthermore, it was found that surface integrity and the tool life fitted within the range of the above-mentioned result, even if the feed rate was increased speed from 5 to 10 times in the state of a constant cutting speed for shortening the cycle time.

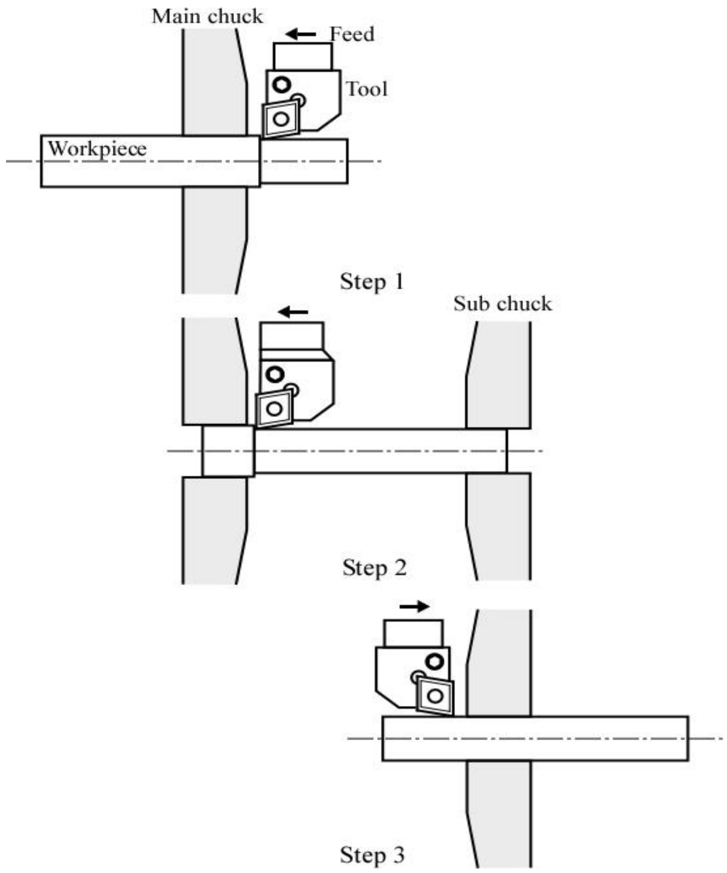

Figure 8. Machining process which was devised secondly

The machining process which was devised first is shown in figure 7. The double chuck was used to hold the workpiece from both ends. The main chuck grasped the next intermediate part after turning at the intermediate. Facing on the sub-chuck side and turning the uncut part from the workpiece at the first stage were carried out in the next step & in the final step, the sub-chuck grasps the intermediate part, facing on the main chuck side and turning the uncut part from the workpiece at the first stage were carried out. The roughing, semi-finishing, and finishing processes cycle was repeated three times. The cycle time was of 369 seconds for these machining processes. The aim of that experiment was to shorten the cycle time. The main chuck grapes the workpiece in the state of 25 mm length projected from the main chuck in the cantilever style at the first stage as shown in figure 8. The sub-chuck pulled the workpiece from the main chuck at the second stage, after turning & facing the region of 20 mm from the end of the workpiece. The turning of the intermediate part 34 mm was carried out after the workpiece was held in the both-end supporting by using the double chuck. In the final step, facing on the main chuck side and turning and facing of 17 mm uncut part of the workpiece were carried out after the sub chuck grasped the intermediate part. The cycle time was shortened up to 134 seconds successfully, in this way. If talking about tool life, the ability for machining with one tool was expanded from 102 rods to 148 rods by changing the machining process of figure 7 to figure 8. The size error was kept below 30 µm at the cutting length L = 300 m by using synthetic emulsion & the synthetic soluble. The finishing process of this valve stem used to be carried out by centerless grinding of the outside order at the unit price of 115 rupees.

IV. CONCLUSION

External turning of Inconel 625 which is the cast-type nickel base superalloy and can be used as the valve stem of the turbocharger parts was carried out by using the large rake angle tools. And the influence of the cutting length on the surface integrity was investigated. The tool wear & the surface integrity were investigated experimentally by comparing the performance of the cutting fluids between the conventional emulsion and the synthetic type. In the result, the tool damage was not seen despite the large rake angle, and good surface integrity, such as the surface roughness, and tool life were obtained. The surface integrity and tool life got worse when the cutting length was so large. As for the cutting fluids, it was found that the conventional type showed poor performance in the surface integrity and tool life than the synthetic emulsion. So, the performance of synthetic emulsion was good. However, it was found that the tool wear was not only to the size error, roundness and cylindricity deteriorated with the large cutting length. In addition, having repeated the improvement of the machining process through the program operating with the opposed twine spindle CNC lathe for more production efficiency led to success in shortening the cycle time, including the machining time, and reducing the cost. Because the life of the synthetic types is double that of the conventional emulsion and the number of waste oil decreases, they may be effective for environmental measures as well as cost performance.

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