Hybrid Machining: An Industrial Case-Study Comparing Inconel718 Reaming and Drilling with Abrasive Waterjet Technology

B. Wanner(✉), A. Archenti, and C. M. Nicolescu

Department of Production Engineering, Manufacturing and Metrology Systems Division, KTH Royal Institute of Technology, Stockholm, Sweden
bwanner@kth.se

Abstract. Abrasive waterjet technology is one of the fastest growing metal cutting technologies. When used in conjunction with conventional metal cutting methods, abrasive waterjet cutting can be both cost saving and environmentally favorable. This paper shows that when processing hard to cut alloys, abrasive waterjet will be an excellent hybrid alternative. Reaming and drilling have traditionally been used to produce turbine blisks. Reaming is a highly expensive method since it uses very large amounts of cutting tools. Especially when cutting hard materials such as Nickel alloys, tools have to be replaced after only a few minutes of usage. By applying abrasive waterjet cutting to part of the process, the cost for tooling can be almost entirely eliminated. It will also increase the return profit for revert material and greatly reduce environmental emissions. This is because reaming and drilling produce chips while large amounts of cutting fluids are being used. Abrasive waterjet cutting will produce one large metal chunk per cut and uses no cutting fluids. This paper presents a method to combine abrasive waterjet cutting with reaming and drilling.

Keywords: Hybrid processing · Reaming · Abrasive waterjet
Machining vibrations · Sustainability

1 Introduction

1.1 Background

Abrasive waterjet technology has been used for metal cutting for many years [1]. However, it has been used in a limited fashion in hybrid applications. Even in research articles on hybrid processing, it is mostly referred to as an independent method. Here it is presented as a method used in combination with reaming, a conventional cutting method using a very large number of cutting tools. Reaming is not only expensive due to tool wear but also creates long down-times while changing tools. Since the material removed is in the shape of chips, revert material is both bulky and produces low returns of investment. It also uses large amounts of cutting fluids creating a non-favorable environmental situation.

Many industrial factors drive hybrid processing forward. One such factor is cost reductions that can lead to long-term savings in both resources and environment.

J. Ni et al. (Eds.): AMP 2018, LNME, pp. 109–114, 2018.
https://doi.org/10.1007/978-3-319-89563-5_8

Revert material handling is a very large cost to manufacturers. A reduction in revert material handling by increasing the value of revert material extracted during the machining process will increase profits. More importantly, it will have a positive effect on the environment. This industrial case study shows how abrasive waterjet can replace part of the manufacturing process and at the same time contribute to several advantages. It is fast and accurate. There is virtually no tool wear. It produces revert material in the shape of large chunks that can be sold back to the material vendor at a much higher return than for chips. Additionally, abrasive waterjet cutting uses no cutting fluids and thereby has no negative effect on environmental sustainability or on the health of the operators. All these factors contribute to abrasive waterjet cutting as being a viable hybrid method to reaming and other conventional cutting technologies.

2 Approach

In the research presented in this paper, Inconel718 was used for the experiment. A 60 mm thick workpiece was cut at various speeds to document quality and time of cut. Nickel-base alloys are extremely hard to cut using conventional cutting methods, and cause severe cutting tool wear. Therefore, abrasive waterjet cutting was used as a hybrid roughing method for the initial cut, removing some 90% of the material. The remaining 10% was left for the intended reaming finish operation. The striation marks were observed from the abrasive waterjet as the jet tends to spread and deviate from the center cutting line during penetration into the 60 mm thick material. The abrasive waterjet was used to assimilate the reaming roughing operation cutting wedges out of the blisk.

Subsequently, it was used to drill 15 mm diameter holes from the Inconel718 workpiece in order to show drilling capabilities. When cutting the wedges, the waterjet started cutting from the periphery of the material in towards the center and then completing the cut from the center outwards towards the periphery at an angle of 15°. This was done at three different cutting speeds, where the speed is defined as how fast the jet is moving across the material. A total of five holes were drilled using abrasive waterjet. In this case, the jet was cutting through the material from a solid part of the workpiece. In order to compensate for jet drift, the jet was permitted to enter at the center of the drilling hole and then during the penetration cut move it to the intended circumference of the hole. The jet was then moved around the circumference to complete the cutting of the hole.

3 Process Methodology

Abrasive waterjet is capable of producing holes of any shape as well as convergent or divergent cutouts. Extremely small diameter deep holes can be produced which often pose significant problems for conventional drilling methods. When cutting circular holes, however, the tendency of abrasive waterjet is to create tapered walls. By lowering the traverse speed, it will compensate for this tapering effect. If the traverse speed is slowed too much, however, there is a risk for the tapering to start moving outward with increasing depth. Instead of slowing the traverse speed, tilting of the nozzle may compensate for the tapering effect. Controlled correctly, this method can correct the tapering effect without affecting cutting speed [2]. Because of economic and environmental aspects, abrasive waterjet cutting has become a substitute for chemical machining, laser machining, electro discharge machining, and spray etching.

In abrasive waterjet machining, water acts as a carrier that dampens the impact effect of the abrasive on the surface. Abrasive particle grit hardness, size, type, and shape all have an effect both on material removal rate (MRR) and on surface roughness. MRR and surface roughness increase if particle hardness is increased. Harder abrasives act as rigid indentors compared to softer particles, making the hardness ratio between workpiece and abrasive important [4]. By increasing abrasive hardness from 500 to 2500 Vickers, the MRR doubles. However, the increase in MRR is only slight above 1000 Vickers. Similarly, surface roughness increases significantly when the hardness increases from 200 to 1000 Vickers and insignificantly above that. The abrasive shape also has an effect on MRR and surface roughness. More evenly shaped particles produce a lower MRR and a smoother surface. Larger abrasives and higher abrasive mass flow rates cut faster.

Reaming is a finishing operation performed with a multi-edge tool producing high-precision holes or complex geometrically shaped cutouts. When the cutout is in the interior of a component, a hole must first be drilled by a different method prior to applying the reaming operation.

When the cutout is at the periphery of a component as in the case of a turbine blisk, reaming may be used also to initiate the cut. Reaming uses a large number of cutters and produces chips similar to milling. It is a relatively expensive and time consuming cutting method. Especially when processing hard to cut materials such as Inconel718, it becomes a highly expensive method. Standard reaming produces circular holes and pull reaming produces virtually any geometrical shapes [3].

4 Experimental Setup

A 3.5 m straight reaming machine was used equipped with some 400 cutting tools. The photograph in Fig. 1 shows how the tools are fed into the blisk material until the finish dimensions are obtained. The waterjet cutting machine was a 2×4 m large table production machine equipped with a 15° tilting head, 0.8 mm orifice, and a sand grit size of 80.

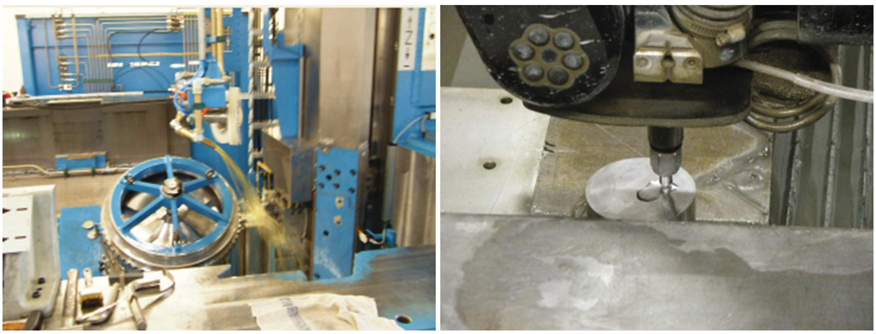

Fig. 1. Reaming setup (left) and waterjet head (right)

5 Results and Discussion

The reaming process cuts a pine tree-shaped opening into the periphery of the blisk. It starts the cut from the outside and works itself into the final geometrical shape, from rough to finish machining. By using abrasive waterjet cutting, the thought is to eliminate the rough machining operation of the reaming process. This will allow for a solid triangular-shaped chunk of material to be salvaged as revert material as opposed to chips. Inconel718 is one of the most expensive alloys used in aerospace applications and the price per pound for solid revert is much greater than for chips. For a blisk with 50–100 machined openings for blades, the savings only in material revert will be very large by using abrasive waterjet cutting instead of reaming. In addition, storage volume for chips is much greater than for solids, thereby saving revert storage space.

Reaming uses large amounts of cutting fluids. These can be completely eliminated during the roughing portion of the machining operation if abrasive waterjet cutting is used. Except for the obvious cost saving, it will contribute to an environmental improvement.

Reaming induces heat and there for stresses into the workpiece with subsequent heat treatment as a consequence. During the abrasive waterjet cutting, virtually no heat is induced into the workpiece. An infrared camera was used to prove the fact (see Fig. 2). The only temperature change during the process is the slight increase in temperature of the water in the tank below the part. This stems from the energy absorbed from the waterjet. The forces and vibrations produced by abrasive waterjet cutting are negligible compared to the reaming operation [5].

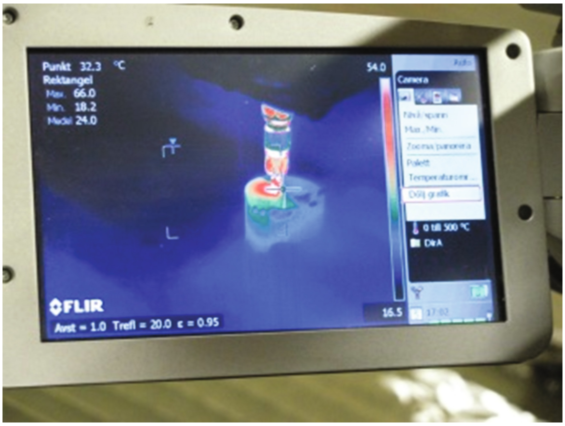

Fig. 2. Temperature measurements during abrasive waterjet cutting

Abrasive waterjet technology uses a crystal and an orifice to converge and shape the jet. For rough machining, an orifice may be used for 50–100 h before replacing. However, the reaming operation requires a large amount of cutting tools, in some cases over 400. When cutting Inconel718, these cutters have to be replaced after only one to four minutes depending on what portion of the cut is being made. Tool replacements are highly expensive and require substantial downtime for the machine. Tool wear also gives rise to emission of unwanted elements into the atmosphere.

Abrasive waterjet cutting is used here as a roughing operation. The quality of cut is therefor not critical. As long as the jet can be controlled to cut relatively straight as to not jeopardize on the final dimensional requirements, the fastest traverse speed possible can be used. Even so, several different traverse speeds were used during the experiments in order to observe quality of the cut surface (See Figs. 3 and 4).

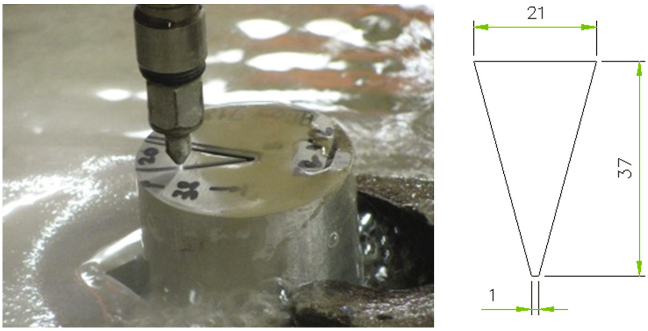

Fig. 3. Waterjet cutting setup and cutting procedure

Fig. 4. Cutting results and surface quality for abrasive waterjet cutting

6 Conclusions

By using abrasive waterjet cutting in combination with conventional cutting methods, increased productivity follows due to reduced downtime from changing conventional tools. Increased material removal rates and improved safety of operations are other benefits. Additionally, the braking of reaming tools or drills at the end of a roughing operation could severely damage the workpiece and therefor have large negative impacts on production costs.

For sustainability, a better control in revert handling, less cutting fluids, and less tool wear will contribute to a better environment. The conventional reaming process produces small chips that require large storage space and complicated cleaning practices when being processed for remelting into new material. Cutting fluids are more environmentally friendly today than ever before. Even so, reaming and drilling requires very large volumes of cutting fluids. These have to be cleaned prior to reuse and it does contribute to a non-desirous environmental situation. The abrasive waterjet cutting method, on the other hand, produces relatively large chunks of revert metal that requires very little processing before remelting. Clear ecological sustainability can therefore be realized by using abrasive waterjet cutting for the roughing operation as opposed to reaming and drilling. As a bonus benefit, chunks of metal have a greater value per pound than chips.

By using an IR camera it was shown that the heat introduced into the workpiece during the abrasive waterjet cutting operation was negligible. There is no additional heat treatment required as a consequence of the roughing operation. This will shorten the process time and decrease the total processing cost.

Tooling cost will be reduced drastically if the hybrid method is used instead of the conventional cutting method by itself. The reaming operation can wear out 300–400 cutting edges within only a few minutes. In the case of abrasive waterjet cutting, the only tooling that wears is the nozzle. There is also a crystal that needs to be replaced at certain interval. However, the tooling cost for abrasive waterjet machining is negligible compared to the reaming machine.

Inconel718 is a very hard to process material. Even so, by using abrasive waterjet cutting, the drilling operation was relatively easy to perform. Virtually no tool wear could be observed. Also in this case, cutting using abrasive waterjet produced a solid chunk of metal.

Acknowledgments. This work was partly carried out at Siemens Industrial Turbomachinery AB, Finspång and Strömbergs Waterjet Company in Gothenburg, Sweden and has been supported by the Centre for Design and Management of Manufacturing Systems – DMMS at KTH.

References

1. Gärdek, H., Ouaha, B.: A State of the Art Report and Comparison with Conventional Methods of Waterjet Machining Technology (2015)
2. Zhang, S., Wu, Y., Chen, D.: Hole-drilling using abrasive water jet in titanium. Int. J. Mach. Mach. Mater. **9**, 47–65 (2011)
3. Wanner, B., Archenti, A., Nicolescu, N.: Hybrid machining: abrasive waterjet technologies used in combination with conventional metal cutting. J. Mach. Eng. **17**(3), 85–96 (2017)
4. Fowler, G., Pashby, I., Shipway, P.: The effect of particle hardness and shape when abrasive waterjet milling titanium alloy Ti6Al4V. Wear **266**, 613–620 (2008)
5. Wanner, B., Eynian, M., Beno, T., Pejryd, L.: Cutter exit effects during milling of thin-walled inconel 718. Adv. Mater. Res. **590**, 297–308 (2012)