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Paper

USE OF PRE-PROFILING A MILLED POCKET AS A MEANS OF IMPROVING MACHINING AND LOWERING ENERGY COSTS

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ABSTRACT

The use of abrasive waterjets has, over the years, become commonly used for metal cutting, and on occasion, has been found effective in milling pockets into parts as part of the manufacturing process. It is possible, using an orbiting nozzle, to achieve satisfactory levels of surface finish and to mill complex geometries. However, the use of abrasive particles to remove the target material as very fine particles is an extremely energy intensive one. As energy costs begin to rise, it is useful to consider other ways in which this tool can be used. Conventional metal milling can induce residual thermal and mechanical stresses into the wall of the pocket that it creates. Thus, by precutting along that profile, the final wall surface can be left in an un-stressed state while the bulk of the material is removed. This technique requires that the abrasive waterjet be able to cut to a defined depth, leaving a high quality along the residual wall that is left. It is shown that to achieve these joint objectives it is better to use a multi-pass high speed cutting, rather than seeking to achieve the total depth required in a single pass. Using this technique, it is possible to leave ribs between pockets that are only 0.5 mm thick. However, even though the chips are larger with conventional milling than with an AWJ system, this process is still energy inefficient. By taking advantage of the ability to cut very deep, accurate and controlled depth cuts in material, it is possible, in some cases, to cut out the milled volume by merely cutting along the edges. The resulting scrap is thus removed as a single piece and can provide feed stock for other parts. Energy use in minimized.

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1. INTRODUCTION

The steadily rising price of crude oil, and consequently gasoline, over the past three years presages the time that oil production each year will no longer be able to increase globally, but will rather reach a plateau and then begin to decline [1]. This increase in the fundamental cost of energy will, in turn, impact the cost of goods, and will force a significant appraisal of the energy costs of doing business. In this regard the common practice of machining metal, in which large volumes of material are reduced to scrap as pockets and unwanted material are removed from the original stock will increasingly be seen as an unacceptable waste of both material and energy. At the same time, the component parts that are made will seek to minimize the material used in their construction, so that the strengthening ribs of material left in the part will be of minimal effective dimension.

At the other end of the manufacturing spectrum, the increased strength and structure of the cutting tools on modern milling heads has allowed the development of faster and powerful machines that can mill material at higher speeds than have previously been possible. However, in the use of these machine tools, the pressures applied to the residual parts and the heat generated during the milling process can induce stresses in the residual ribs of material that are left in place, requiring that these need to be left thicker than the design might otherwise call for in order to provide adequate resistance to the milling tool, or that secondary processing be used to remove this affected zone.

The use of an abrasive waterjet (AWJ) system to cut precise parts to the required final dimension has been documented earlier [2]. Use of this tool has the advantage that it allows through-cut parts to be isolated without destroying the central material, which, as a solid piece of material, can then be used as stock for the creation of additional, albeit smaller, parts. As an illustration of this consider where a chamfered hole is cut through titanium (Figure 1). While the stock left as a single piece is, in this case, of only limited use, it does illustrate the point that the solid rod left has potentially more use than the equivalent pile of metal shards left from a conventional drilling operation to create the same hole. Cutting the edge profiles to the required geometry can, however, limit cutting speeds, particularly in thicker and harder materials, to less than 10 cm/minute.

In contrast with those requirements, consider the case where the jet is not required to make a through cut. At the slower cutting speeds required to achieve these depths in a single pass, it becomes more difficult to achieve an even cut, and the lower segments of the cut, and the bottom profile are often left rough and out of tolerance (Figure 2). Thus, conventional cutting of the wall edge in a single cut is not the most effective way to achieve the desired profile.

Work in Sardinia [3] has suggested that as cutting speed is increased, so that the cut depth is achieved in a series of passes, rather than just by one pass, that the edge quality of the cut can be restored. Accordingly, a short experiment was carried out to determine if this would be the case in cutting titanium.

2. EXPERIMENTAL DETAILS

A 280 MPa, AWJ cutting stream was used in a series of linear passes over a sheet of titanium 10 mm thick. Pass speed was initially slow (2.5 cm/min) but was steadily increased to 250 cm/min, with traverses over the sample repeated until the part had been cut through. The time taken was determined from the number of passes required for penetration, and from this the depth removed per pass could be determined.

It was noted (Figures 3, 4 & 5) that as the speed of traverse increased, the quality of the surface first became rougher, and then as the depth achieved per pass was reduced, became smoother again, until an acceptable surface quality was again achieved at a speed above 250 cm/min.

The depth:speed relationship could be plotted from the data obtained (Figure 6) and this followed quite well the relationship:

$$\text{Depth} = \text{const} / (\text{traverse speed})^{-0.8}$$

3. BULK REMOVAL OF MATERIAL

As these cuts were made it became clear that not only were the walls of the cut becoming smoother at the higher speed, but concurrently so was the floor of the cut that was being achieved. This could have been anticipated since, in the earlier work that has been reported by us in this field [4], results showed that a high speed traverse of a waterjet milling tool over the surface could generate a smooth base to a milled pocket (Figure 7).

An illustrative test of this technique to cut out a strip of titanium was then made, with the cuts on two sides being made as a series of passes that would bring the cut depth down to a designated level on each side of the piece to be removed, so that it would remain intact, and available for further use, while cutting the main stock piece to a desired shape (Figure 8).

4. PRE-PROFILING A MILLED POCKET

In the same way as with the above example, this technique allows profiling cuts, to a designated depth, to be cut into a piece of stock, outlining to depth, the profile of a desired pocket. Because the wall is isolated from the main block of stock in the body of the pocket, that bulk material can be removed by a high-speed end mill without the mill coming into contact with the wall that has been left (Figure 9).

This has two advantages. The first is that the residual wall is not exposed to the temperatures and deforming stresses that might be induced into that part from the forces and friction generated by the high-speed tool, and thus no secondary processing of the wall will be required. The second advantage falls out from this, and is that the intervening rib between two pockets can be cut to a very narrow thickness (1 mm in the example sample – Figure 10), and does not have to withstand the cutting conditions for the bulk of the material beside it.

5. CONCLUSIONS

By using a higher traverse speed for an AWJ (or ASJ) nozzle over the surface of a part to be profiled it is possible, by using multiple high-speed passes, to achieve a cutting slot with both smooth walls and a controlled depth along its length. This allows pieces of stock to be recovered from the cutting and milling operation in sufficient size that they can be used as material for the creation of further parts, without needing to reprocess the fragmented pieces back to solid metal first – a considerable energy and cost savings.

In addition, by using this controlled depth of cut in stock, the walls of milled pockets can be pre-excavated in the material allowing the use of a high-speed mill without the need for concern over the condition of the wall of the pocket after the milling process is completed.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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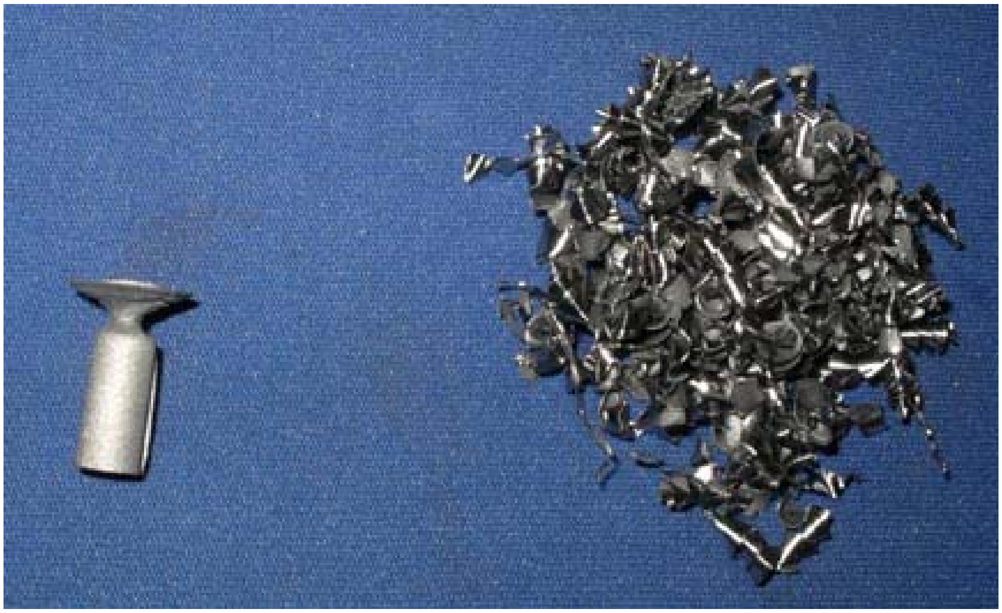

Figure 1. Chamfered hole remnants as cut (a) as a single piece using AWJ (b) as chips.

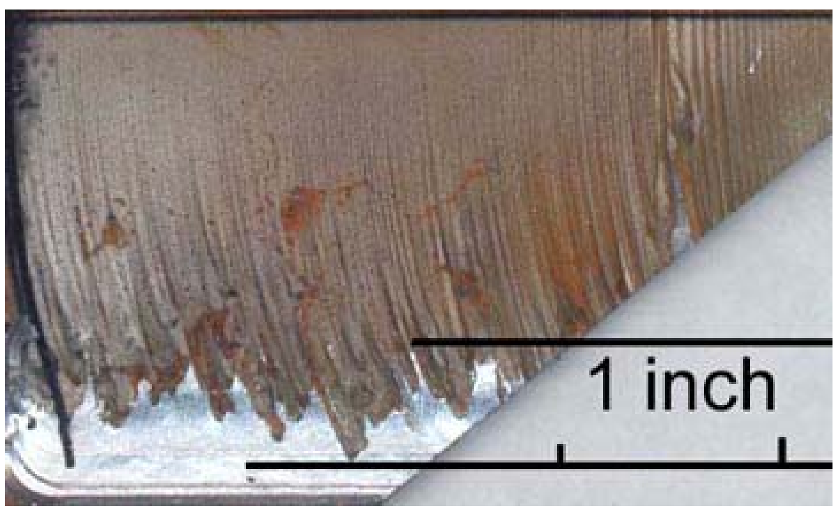

Figure 2. Sectioned cut in steel to show the variable level of the bottom of the cut.

Figure 3. Cut edge quality at 5.5 and 10 cm/min speed.

Figure 4. Cut edge quality at 20 and 40 cm/min speed.

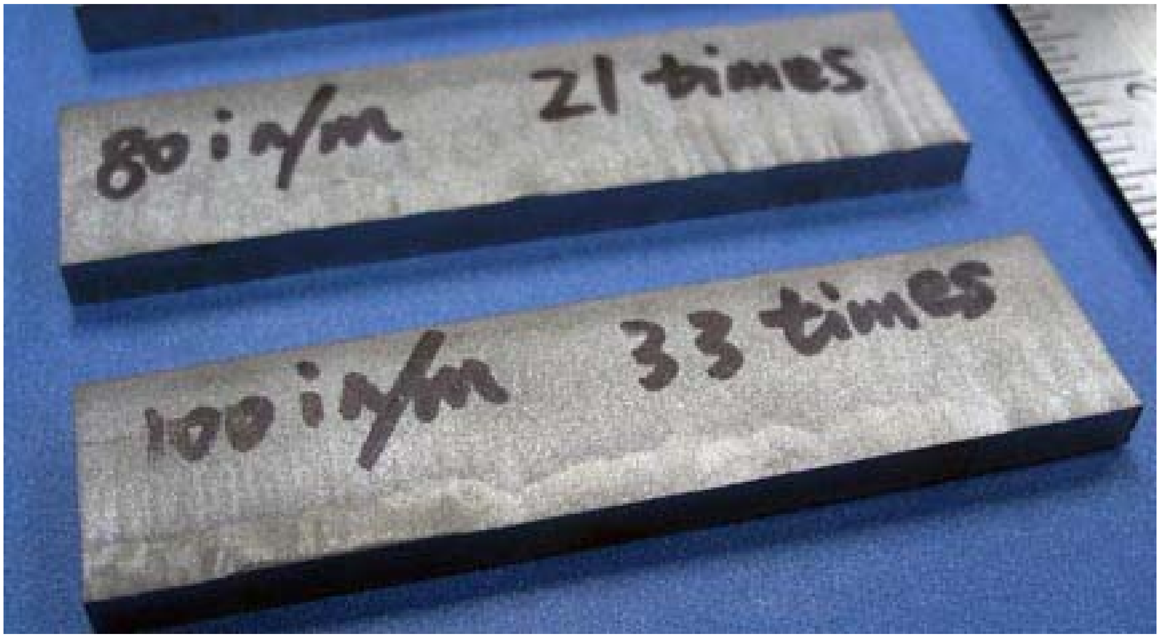

Figure 5. Cut edge quality at 200 and 250 cm/min cutting speed.

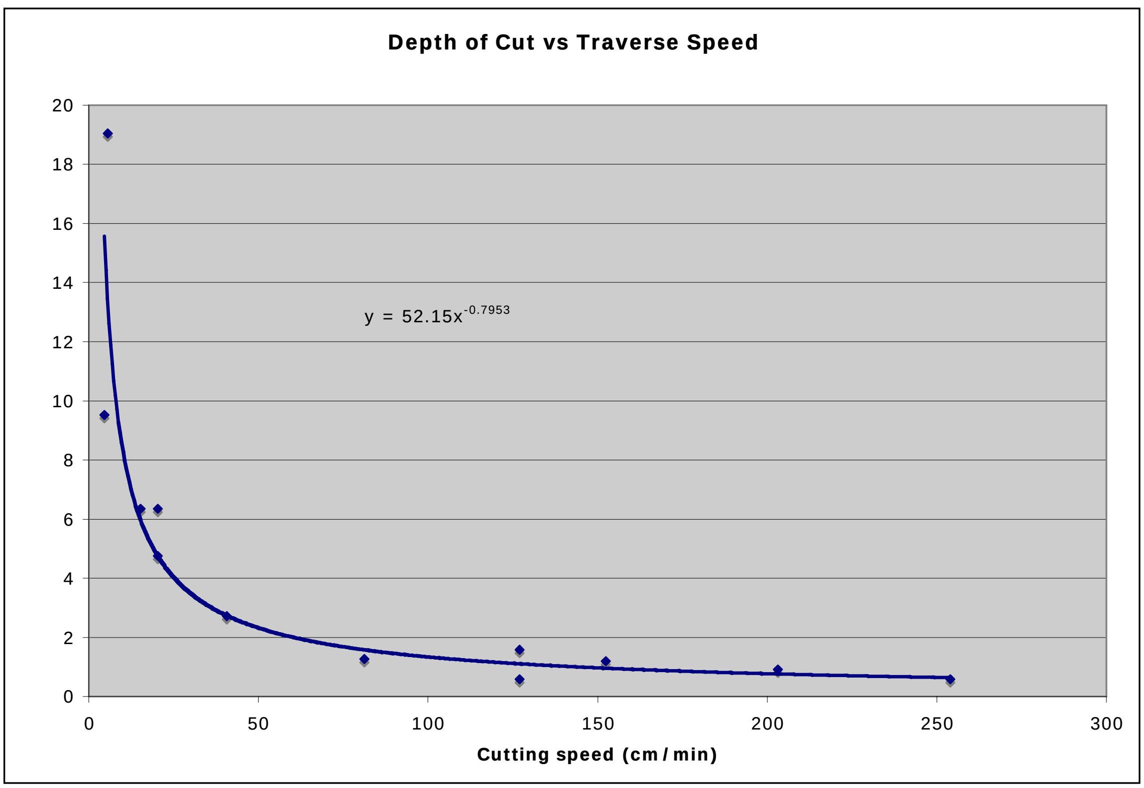

Figure 6. Depth of cut as a function of cutting speed for multiple pass cutting.

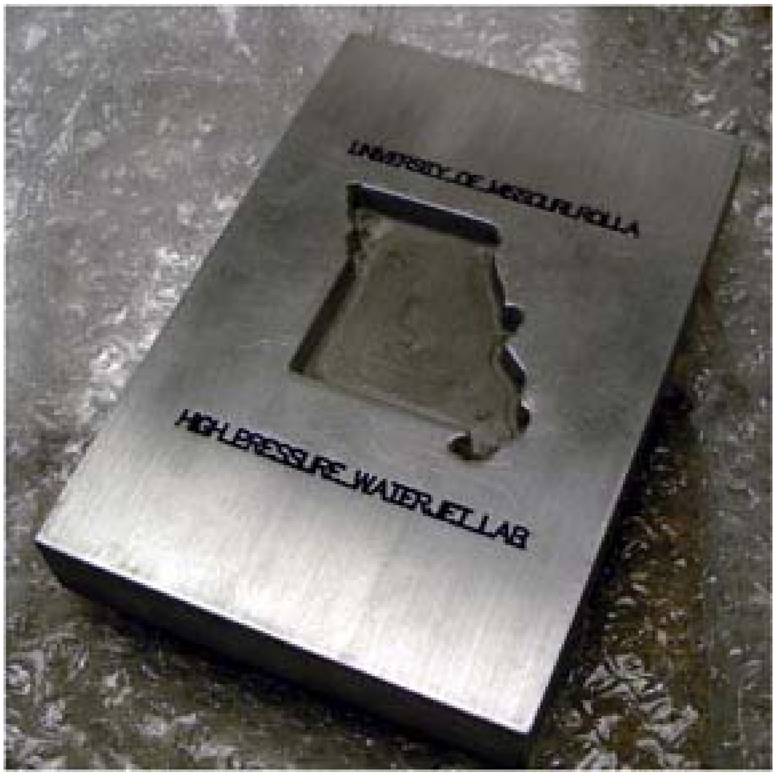

Figure 7. Milled map of Missouri showing the flat bottom of the milled pocket.

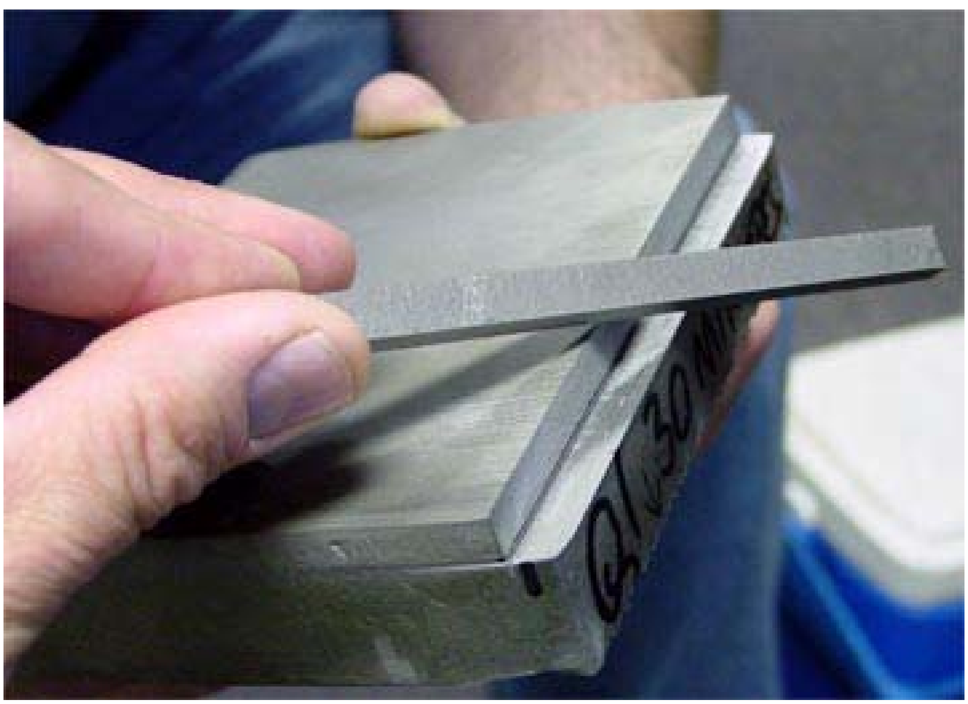

Figure 8. "Scrap" material removed by cutting both sides to controlled depth.

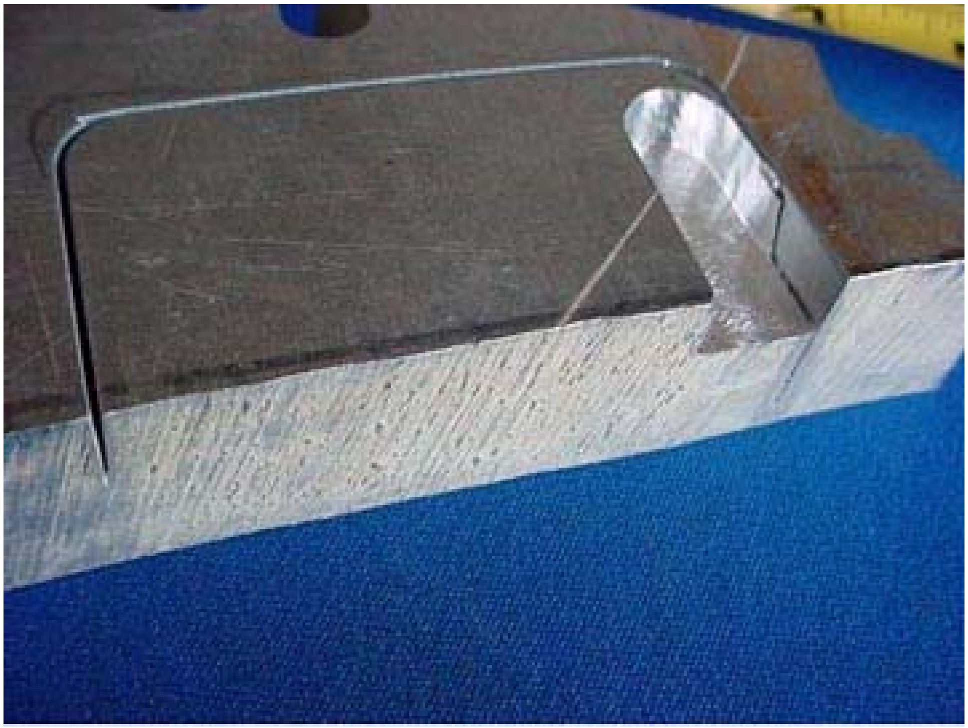

Figure 9. Pre-profiling the outside of a pocket prior to milling to remove the bulk of the material.

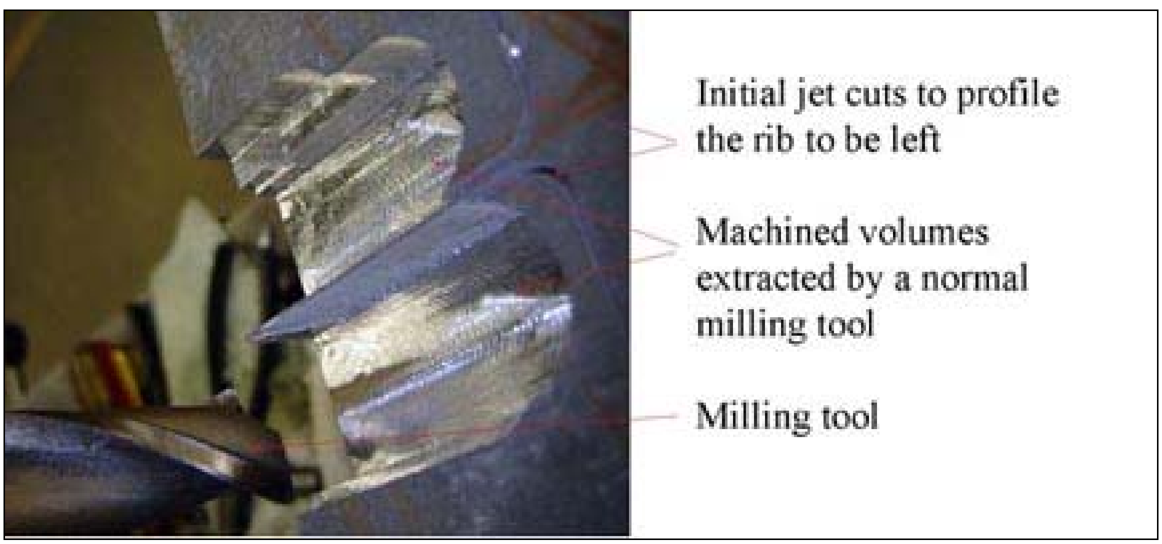

Figure 10. Pre-profiling both sides of the rib, to leave a rib that can be only 0.5 mm wide.