Laser Assisted Machining of Hard-to-Wear Materials

by

Kelly Armitage A/Prof. Syed Masood A/Prof. Milan Brandt Chalapi Pomat – Weir Warman Ltd.

Abstract

This research is being conducted at the Industrial Research Institute Swinburne (IRIS) in cooperation with Weir Warman Ltd. The research commenced in March 2002 and is expected to be complete by March 2004. The purpose of this research is to find out if laser assisted machining of hard-to-wear materials used by Weir Warman Ltd. for slurry pump inners is feasible. And if so, find the optimum operating parameters for minimum machining time and tool wear. If successful, laser assisted machining could be implemented at the plant giving cost savings. As this research has only been conducted for a few months, this paper contains only a preliminary literature review and the proposed methodology.

1. Introduction

The collaborating company in this project, designs and manufactures high quality slurry pumps for mining and other industries. Slurry pump impellers and inner casings need to be very wear resistant because they are used to pump highly abrasive and corrosive slurries of metal particles with other liquids. Weir Warman Ltd. uses some very hard-to-wear materials for these pump components including, high-chromium white cast irons, chrome-molybdenum white cast irons and the Ni-hards. They have also developed and patented a new cast iron alloy called HYPERCHROME®. All of these metals have hardness values ranging between 600HB and 750HB, making them extremely difficult to machine using traditional cutting methods.

Laser Assisted Machining (LAM) is a new and innovative way of machining hard-to-wear materials, which are difficult to machine using conventional methods. LAM combines laser technology with traditional machining methods such as turning and milling. The laser is used as a heat source with the beam focussed on the unmachined section of the workpiece directly in front of the cutting tool (e.g., Figure 1) The addition of heat softens the surface layer of the material, so that ductile deformation rather than brittle deformation occurs during cutting.



Figure 1 – Laser Assisted Machining

There has been much research conducted into the feasibility of LAM in recent years. Much of this research has been specific in its application, with the majority of it using CO_2 Lasers on ceramic materials, such as Silicon Nitride (König & Zaboklicki 1993, Rozzi et al. 1998). There has been little research conducted on LAM of metals, especially the hard metals used at Weir Warman Ltd.. The purpose of this research is to determine if laser assisted machining of the hard-to-wear materials used at Weir Warman Ltd., is feasible. An Nd:YAG laser will be used for all experiments. As this research only began a few months ago, this paper contains only a preliminary literature review and the proposed methodology.

2. Industrial Implications

The mining industry in Australia is one of the countries largest manufacturing groups and exporters. Weir Warman Ltd. is a world leader in slurry pumps, manufacturing and selling throughout Australia and the world. Mining industries, which use their pumps include, copper, iron, aluminium, cement, palm oil, paper and pulp, uranium, water and sewerage as well as many other chemical and metal industries.

Any improvement in performance, efficiency, lifespan, design and manufacturing of these slurry pumps will be of direct benefit to the Australian economy, which depends greatly on the productivity of its mining sector. It is expected that LAM will increase tool life and reduce machining time, thus reducing the cost to manufacture parts. It may also make it possible to machine extremely hard materials, which currently cannot be used because the cost to machine is too high. This means pumps with a longer life can be manufactured. All of these benefits will flow through to benefit the mining industry worldwide.

3. Objectives

The main objective of this research is to investigate and develop techniques for the laser assisted machining (LAM) of hard-to-wear materials manufactured at Weir Warman Ltd.. Existing research has been conducted on LAM of ceramic materials such as Silicon Nitride with favourable results. However, there has been little research conducted in the area of LAM of hard metals such as those used at Weir Warman Ltd..

The desired outcomes will be a documented method of Laser assisted machining of hard-to-wear metals and the optimum operating range for parameters when laser assisted machining high chromium white cast iron. Optimum operating parameters will provide:

- Minimum surface roughness
- Minimum subsurface defects
- Minimum tool wear/ tooling costs
- Minimum machine time
- Maximum material removal rate
- Maximum precision and accuracy.

4. Conventional Cutting methods

Traditional methods of machining hard-to-wear materials include, grinding or diamond machining which accounts for 60%-90% of the final cost of the product (Chryssolouris, Anifantis, *et al.* 1997) Another method used is hard turning, where cutting speeds are increased greatly and a cubic boron nitride (CBN) tool is used. At these high speeds friction heat anneals the material directly in front of the cutting tool, which is then removed by the tool itself, leaving the machined surface unaffected (Albert 1996a). However CBN tools are expensive and it is estimated that Weir Warman Ltd. tooling costs are very high.

It was recognised over 100 years ago that hot machining might make finishing hard materials easier. In 1898 Tilghman (Konig & Zaboklicki 1994) filed a US patent to use electrical resistance to heat a workpiece while cutting. It is not known if his experiment was successful however many people have followed his example and investigated hot machining using various different heating methods. Some of these include induction coils, gas torches, resistance heating and plasma arc heating. However Konig & Zaboklicki noted that for hot machining to be most effective there needs to be sufficiently large heat transferred to a small area directly in front of the cutting tool which most of these methods do not do effectively. The laser overcomes this problem providing a highly localised heat source with high power density.

Direct laser machining has also been researched as a means of shaping hard materials. However it involves melting or evaporating the material, which can cause surface cracks and undesirable changes to the surface microstructure.

5. Research Outcomes

5.1. Temperature

In LAM ultimately it is the temperature of the workpiece, which is most important. Knowledge of the surface temperature and temperature distribution is also essential in the online control of the laser.

There has to be enough heat to soften the surface layer of the material so that ductile deformation occurs during cutting. However there is to be no melting the material, heat treating the bulk of the workpiece or softening the cutting tool, as these are all detrimental to the surface integrity of the finished workpiece. For this reason heating should be localised as much as possible to the surface layer of the material which should be removed before substantial heat is conducted into the bulk of the workpiece. It is not surprising that König and Zaboklicki (1993) noted that knowledge of the temperature distribution at the surface and in the depth of the cut is essential when determining optimal cutting parameters. Rozzi et al. (1998) have conducted much research into the distribution of heat through out a rotating Silicon Nitride workpiece subjected to LAM. They created a transient three-dimensional numerical simulation, which was then compared to experimental data, and a two zone approximate model was produced. They found that under their operating conditions a preheat phase was needed initially to get the material up to the required temperature for ductile deformation. The numerical model showed that thermal energy generated in the cutting process significantly increased the surface temperature however the majority of this thermal energy was removed with the chip with a small amount being conducted into the unmachined workpiece. Thermal energy generated in the shear zone is increased or decreased by changing the cutting parameters such as feed rate, depth of cut, etc.

5.2. Surface and subsurface integrity

Rozzi, Pfefferkorn, et al. (2000) found that for Silicon Nitride, surface roughness results after LAM were mostly consistent, indicating that surface temperature and surface roughness are relatively independent. Further research by Lei, Shin, *et al.* (Nov 2001,) proved that it was the size and distribution of the Silicon Nitride grains in the ceramic material that had the most effect on the surface roughness. This is true for ceramic materials but may not be so for white cast irons.

Barnes, Pashby & Mok (1996b) analysed the resultant tool wear and surface roughness when machining preheated Aluminium/SiC metal matrix composite. Their results show that surface roughness decreased with increasing temperature of the workpiece to a point. However at higher temperatures the surface roughness increased.

As for subsurface cracks Rozzi *et al.* (2000) found that LAM of Silicon Nitride produces no detectable cracks and that the fracture strength is equal to or greater than that produced by grinding.

5.3. Tool Wear

The cost of tooling when machining white cast iron is the main justification of this project. Many research projects contain some element of tool wear analysis with the majority finding that tool wear increases with increased temperature. König & Zaboklicki (1993) found that in laser assisted milling of Stellite 6, tool wear was reduced by 90% compared with conventional milling. Further research conducted by Özler *et al.* (2001) found that when hot machining austenitic manganese steel the tool life increased with increasing temperature but decreased with increasing cutting speed. It was also noted that increased feed rate resulted in decreased tool life. Mukherjee & Basu (1973) cite many examples of investigations which agree with these results. They also state that there is an optimum temperature above, which the tool life decreases. It is suggested that it is at this temperature that the tool begins to soften.

On the other hand Barnes et al. (1996b) found that increasing the machining temperature of Aluminium/SiC metal matrix composites resulted in a decrease in tool life. They claim that the increase in workpiece temperature reduces the built-up edge (BUE), which protects the tool rake face from wear. These differences could be attributed to the fact that all three experiments used different workpiece materials and cutting tool. None of them used cubic boron nitride, which is the tool that will be used in this research.

6. Methodology

There has been much research conducted in the area of laser assisted machining and hot machining but there has been no investigation as to whether it is feasible for the hard-to-wear materials to be used for the sort of slurry pumps produced by the collaborating company.

Initially, samples of AS2027 A05 high chromium white cast iron will be machined conventionally, using CBN tools and Weir Warman Ltd. machining parameters to create a standard. Surface temperature will be monitored with a laser pyrometer and the final surface roughness and tool wear will be analysed.

The next step is to begin laser assisted machining of the sample using the average surface temperature recorded during conventional machining as a starting point. The following variables will be individually altered:

- Rotational speed
- Cutting speed
- Feed
- Depth of cut
- Laser distance from cutting tool
- Laser beam diameter
- Laser power.

And their effect on the following will be analysed.

- Surface temp
- Cutting forces
- Tool wear
- Surface integrity

Once relationships have been analysed, optimum-operating parameters for laser assisted machining of Weir Warman Ltd. hard-to-wear materials will be established. If time permits it is also hoped to trial LAM with cheaper tools rather than CBN tools.

7. Conclusion

Research to date has shown that laser assisted machining is feasible in many applications however further research needs to be conducted before it can be implemented in industry.

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