PART FABRICATION USING LASER MACHINING AND WELDING

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Abstract

This paper describes the current work on a laser cutting and welding system for the fabrication of prototype parts in mild and stainless steels. The relationship to other rapid prototyping systems and to laminated tool production techniques is discussed, the progress to date is described. Difficulties with current welding procedures are outlined and alternative joining techniques are considered.

Introduction

Despite the tremendous progress made in the whole field of rapid prototyping and the development of processes, the majority of systems remain concentrated on non metals. However work is now being carried out on laser sintering of mild steel and stainless steel powders as well as on 3-D welding processes (1,2). Success in these developments will expand on the current prototype possibilities by enabling the direct production of prototypes in metal, when this is required. This will offer benefits in certain situations, cutting out the need for secondary processing of plastic or wax prototypes, such as in producing investment casting moulds.

Laminate Processes

Work at Dundee has centered on using a laser machining centre to cut and fabricate components in mild and stainless steels, using layer cutting procedures and joining techniques. Work in a similar area is also being undertaken by a European consortium under the BRITE initiative.

There has been considerable work in the field of laminating laser or EDM cut sheet and plate to form tooling such as injection mould cavities (3), drawing dies (4) and blanking tools (5,6). These tools have then been exploited in a number of ways for various applications. The motives for the undertaking of this type of work have been varied, and not all in prototyping, but in all cases reductions in production or development times and costs have been realised.

A recent paper by Glover and Brevick (3) argues that whilst current commercial rapid prototyping systems such as Stereolithography, Selective Laser Sintering Laminated Object Manufacture and Fused Deposition Modelling, have their place in the early stages of design, they rarely provide a full range of pre-production information. For example the prototype material is rarely the same as the required part, production processes, and therefore mechanical and physical properties of the prototype, differ from those intended for production, and prototype tolerances and surface finishes are not usually representative of those obtainable by the eventual production processes.

Many of these points are substantive and undoubtedly there are applications and potential for the further exploitation of laminated tool manufacture in a variety of areas.

The drawback, if it can be called that, is that much as the "conventional" rapid prototyping techniques require secondary processes to produce a metal part, the laminated tool production processes by their very nature do not result in a part until the tool is then used in a production situation. Thus most of the applications of lamination have meant using at least one additional process in the creation of the part.

However the process is very useful when the tool is required for a proven process and product design, perhaps replacing and old or worn tool, but clearly it is not so advantageous at providing a first stage prototype part. A process which could produce parts or tooling as required, directly in metal, would generate considerable interest.

Part Fabrication by Lamination

As previously stated work at Dundee is aiming towards metal prototype part production, in a direct process, in a similar way to the 3-D welding work, but here using lamination and fabrication techniques.

The objective is to produce parts in a layer by layer manner where each layer is cut in turn from plate or sheet by laser machining, and the layers are then joined by laser welding. In respect of the joining technique, the process differs significantly from most laminated tool processes. Laminated tool techniques almost all use mechanical locations and fixtures to hold the assembly together. Clearly when dealing with tooling this is a sensible and straight forward approach. Most tool systems allow for this type of fastening by having a significant "flange" area around the tool or cavity, as indicated in Figure 1, to allow bolts or fastening screws to be used. The fastenings being located such that they do not interfere with the operation of the tool.

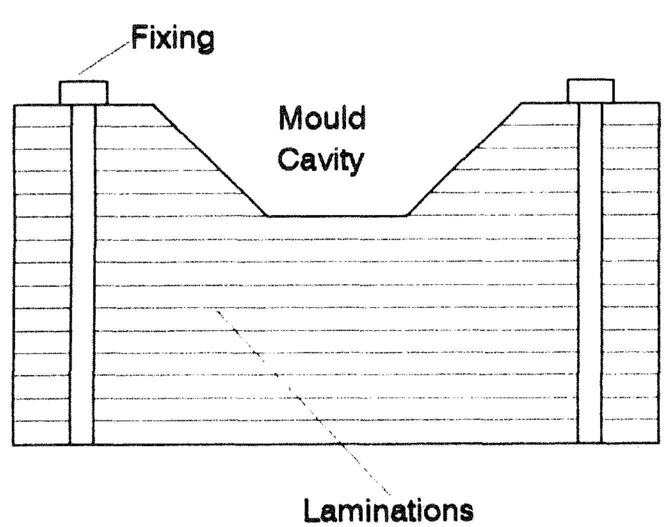

Figure 1. Typical arrangement for holding/fixing laminated tooling.

This approach could also be acceptable in prototyping of large solid parts but it is not suitable for fabricating parts with complex geometries, thin walls or webs or hollow sections.

Laser Cutting

The laser used in the work to date is a "Ferranti MFK 1000" 1000W Co_2 gas laser. Cutting profiles are currently being programmed using an Anorad X-Y control system. The laser machining centre is shown in Figure 2.

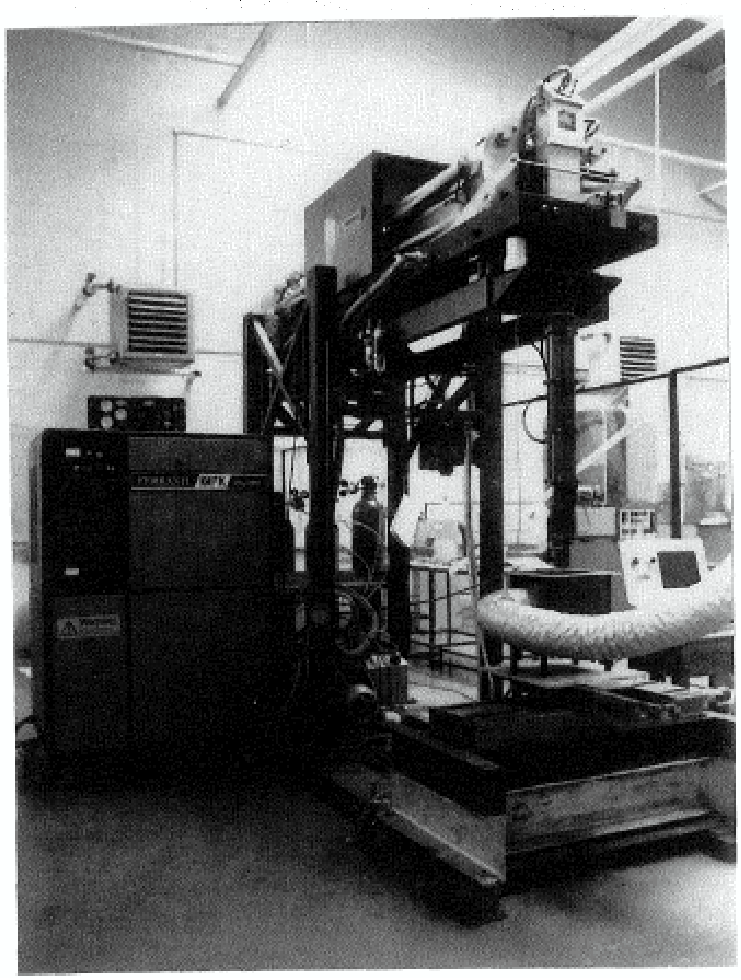

Figure 2. Ferranti MFK 1000 CO_2 laser

To date the materials used have been 18% Cr 8% Ni ASI 304 stainless and medium carbon mild steel, in thicknesses of up to 2mm. A full investigation of the limiting values of cutting speeds possible for a variety of sheet thicknesses and material types is yet to be carried out, but cutting speeds are entirely satisfactory without pushing the system to anywhere near its limits. Typically a cutting speed of 1 metre per minute is used with a pulsed beam of 20 x 10^{-5} s. on and 20 x 10^{-5} s. off, with oxygen assist gas at a back pressure of 2 bar. Figure 3 shows representative examples of laser cut geometries, in this case in 1mm thick stainless steel.

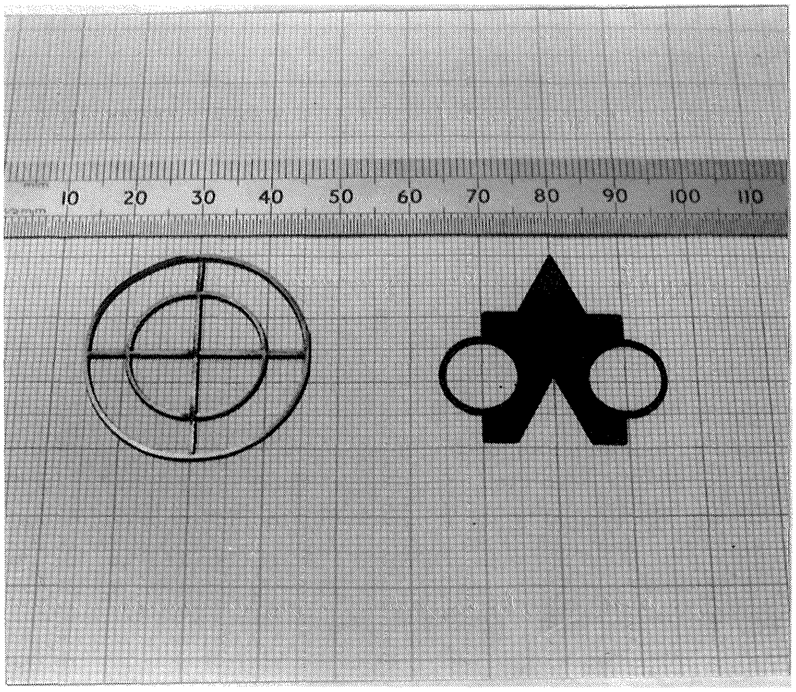

Figure 3. Laser cut parts in stainless steel

Laser Welding

The laser welding aspect of this technique is now the main focus of attention since weld performance and quality are not yet at a level to make the laser cutting and welding route viable as a process. Conventional keyhole laser welding procedures have proved difficult due to the focused beam tending to cut rather than weld. Also the narrow beam means that multiple weld tracks are required to join the layers uniformly. Complete section welding is also desirable to take advantage of obtaining homogeneous or near homogeneous material properties throughout the artifact. Excessive oxidation also resulted in some trials largely due to using compressed air as the assist gas, this should be considerably reduced by using helium gas.

Welding trials were also conducted using a much broader defocused beam, in an attempt to produce a uniform broad conduction weld across the wall section of the parts. This technique shows promise in trials, using a straight weld on large sheet, with the beam focused 50mm off the job, a feed rate of 150mm/minute and 20/20 pulsing it was highly successful. However it was less successful, when using smaller finer laminae, due to problems associated with work holding, heat dissipation and distortion.

Experimentation with welding parameters and development of a system are ongoing and in addition alternative joining methods such as soldering, brazing and structural adhesives are being explored. Figures 4, 5 and 6 illustrate some test pieces which have been laser cut and adhesively bonded together.

Figure 4 shows an approximation of a 60mm diameter sphere fabricated using circular layers of 2mm thick mild steel sheet. This specimen is made up of some thirty layers. The "stepping" observed in the polar regions indicates that for a sphere of this diameter the 2mm thick material is substantially too thick to give a smooth curvature in these zones.

A further stage of development of this system would be to have various thicknesses of sheet available to optimise the build. For example vertical sections could be cut from relatively thick material thus minimising the number of layers and therefore the number of welding/joining operations necessary, whilst complex geometries and tight radii could be better and more accurately built using thinner layers.

Figure 5 shows a square based hollow pyramid section built from thirty four layers of 1mm thick stainless steel. The sides of each layer are 1mm shorter than the previous layers. The total cutting time for this part was approximately 10 minutes.

Figure 4. Sphere, produced in 2mm mild steel.

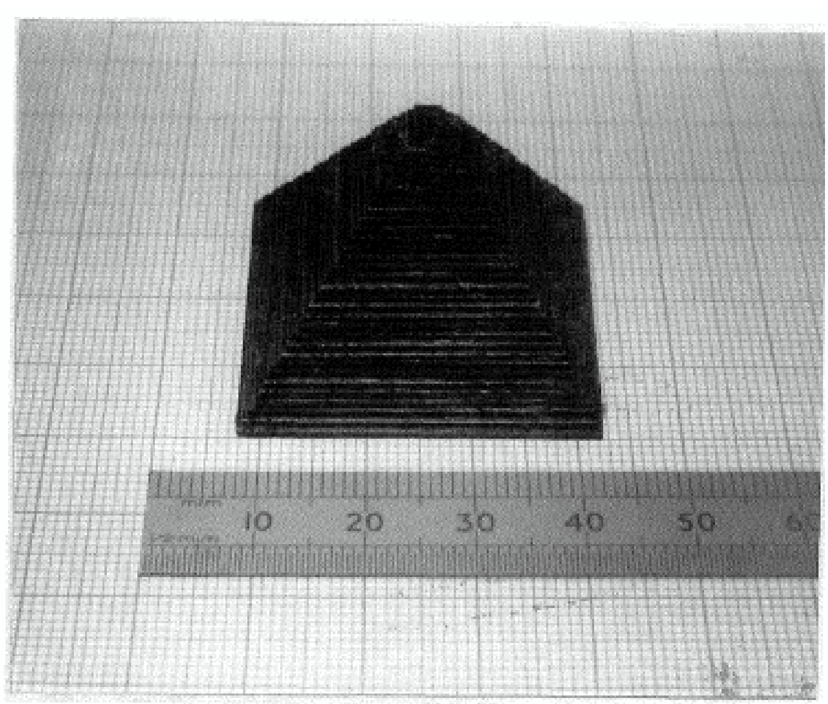

Figure 5. Square based hollow pyramid in 1mm thick stainless steel.

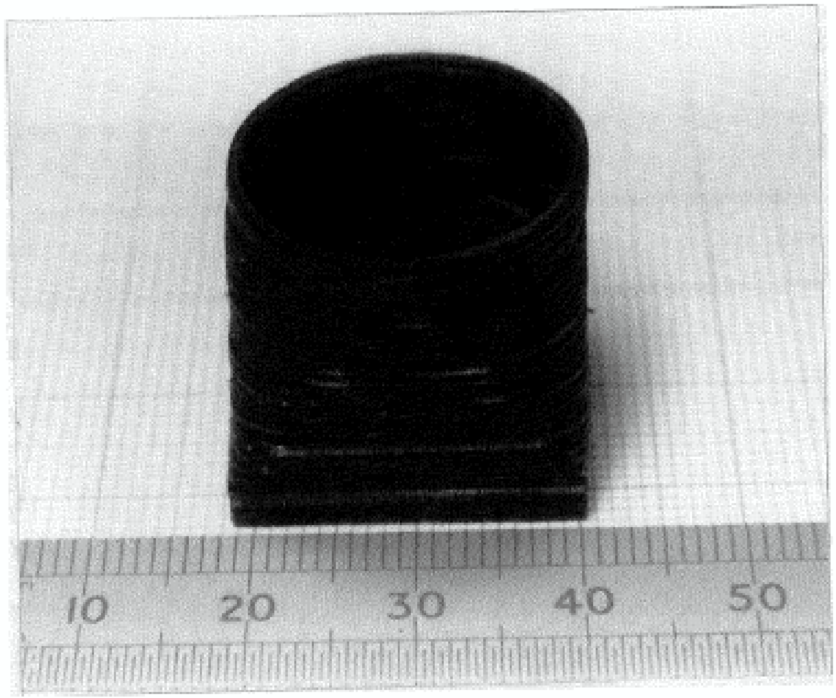

Figure 6. Square to circle transformation in 1mm thick stainless steel.

The section illustrated in Figure 6 is produced in 1mm thick stainless steel and has a wall thickness of 1mm. Over a height of 22mm the section transforms from a 22mm side square to a 22mm diameter circle. This section could, for example have been produced using thick (*e.g* 5mm) plate for the square base, thin sheet for the transformation region and then reverting to thick section to build on the circular geometry.

Future Developments

Clearly a number of areas in this work require considerable further investigation. They include:

1. Development and understanding of required welding conditions, if this technique is to be pursued as the joining method.

2. Evaluation of alternative joining methods. Suitability in terms of strength, ease of production and versatility will dictate possibilities.

3. Automation of layer feed, selection and alignment; currently each layer is cut individually and when all the layers are prepared they are joined. In a viable system the joining operation would be integrated and synchronized with the cutting operations so that each layer is joined immediately after it is produced.

Conclusion

Laser cutting and welding offers potential as a means of directly fabricating a prototype part in metal. Further development, particularly in the area of laser welding is underway. A fully developed system will help service a requirement for prototypes which may need to display high levels of mechanical properties, high thermal or electrical conductivity or have the weight and feel of the planned metallic production material.

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