PRODUCTION OF METAL PROTOTYPES USING A HIGH POWERED LASER MACHINING CENTRE

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Introduction

The established commercially available rapid prototyping techniques are now well known throughout the manufacturing community. They are able to produce high quality, accurate prototypes, but are limited largely to processing polymer, wax or paper materials. Where a metal part is required, then a further process step, such as investment casting using the prototype part as a pattern is required. As a further point most of the above systems are high capital cost dedicated pieces of equipment.

This paper describes the use of laser machining centres as rapid prototyping tools in the areas of, laminated prototyping, using both paper and metal, and laser forming.

Laminated Prototyping

For a number of years there has been a considerable amount of work done, particularly in Scandinavia and Japan, in producing laminated tools and dies(1). The principle is simple and essentially involves assembling a series of laser cut profiles and mechanically fixing them together.

Laminated prototyping is an adaptation of this technique to produce parts rather than tooling and trials have been carried out using both paper and sheet steel.

Laser Forming

Laser forming is a relatively new technique(2). It involves using a high powered laser to track over the surface of a sheet of metal, the track being defined by the required geometry of the part. The laser parameters are set in order to soften or melt the upper surface of the metal whilst the lower surface is essentially unaffected. The upper surface is then allowed to cool, cooling may be forced or natural, and as it does so there is a contraction, which causes the sheet to deform. Depending upon the specific laser parameters, it has been found that a fold of 2 degrees from flat is a typical of the deformation that can be expected from a single pass.

Experimental Results

Laminar Prototyping. There are essentially three stages involved in laminar prototyping; laminar geometry generation, profile cutting and joining of laminates.

Work at California Polytechnic State University has been carried out using 1.5kW CO_2 laser machining centre (3) and paper, polymer and sheet steel parts have been produced. One of the first parts processed was a model of a window frame extrusion. As can be seen from Figure 1 the part is relatively complex, the geometry was encoded in CADKEY and SMARTCAM was used to generate the laser tool paths. The component layers were cut from 2.0mm New Board and laminated using a spray on contact cement. Each layer took approximately 30 seconds to cut and a five layer part was manufactured in under 5 minutes. A similar part has also been produced using polymer sheet (see Figure 2).

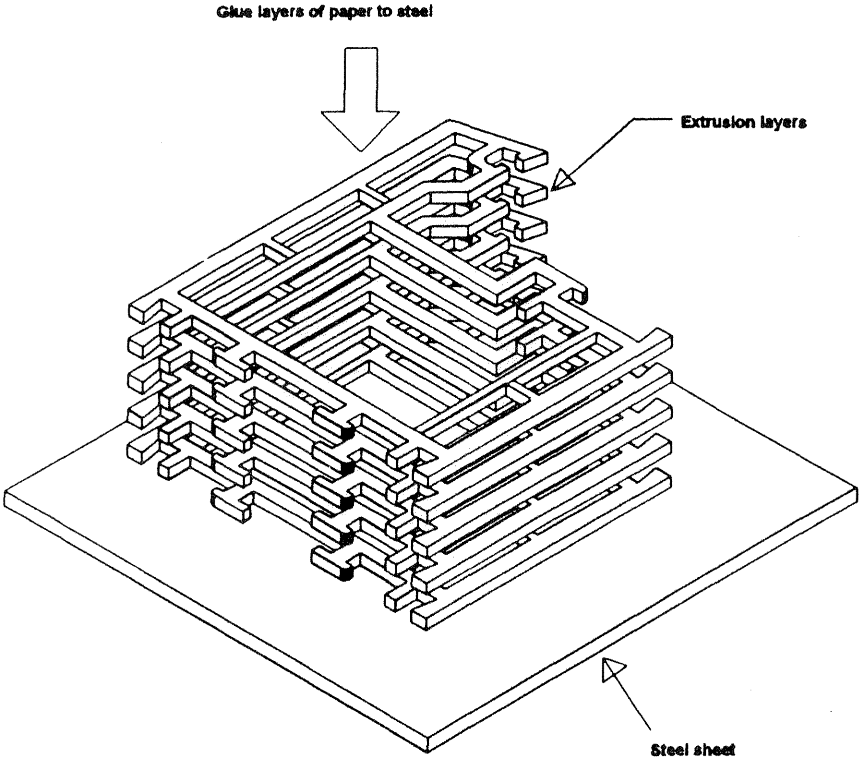

Figure 1 - Window Frame Extrusion

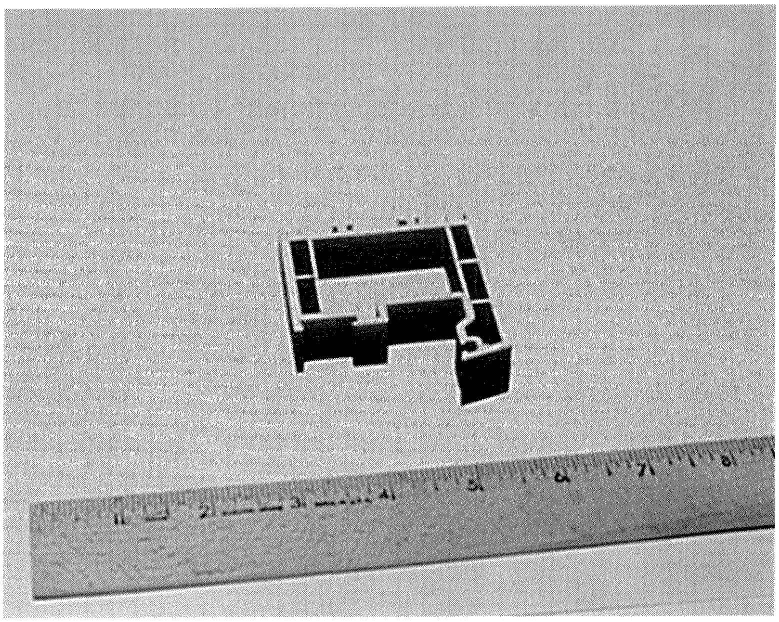

Figure 2 - Window Frame Extrusion Model Produced in Polymer Sheet

A similar technique was used to create a prototype golfclub head, (see Figure 3) the layers of this part were produced in both paper and sheet steel, as yet the steel layers have not been joined, however there are a number of techniques which could potentially be used to do this including laser welding, brazing or soldering and adhesive bonding.

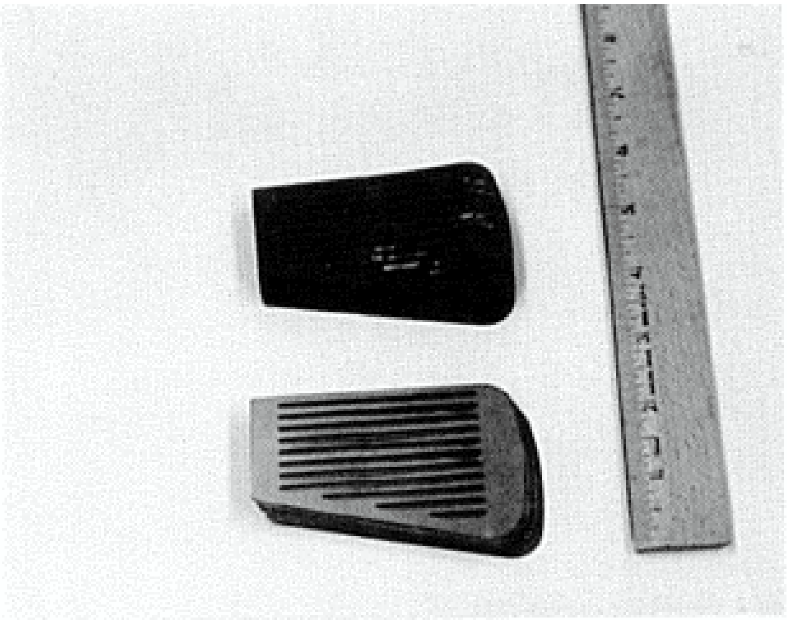

Figure 3 - Golfclub Head

Work at the University of Dundee has shown that in practice conductive laser welding has proved difficult(4). The main problem being that in small laminae it is extremely difficult to dissipate the excess heat rapidly enough to avoid warping of the part. This problem is exaggerated by the desire to join the laminae, not just at the edge, but all over the surface area. A further problem is the limited power of the laser being used. It is however possible that conventional or laser spot welding may be practical as a joining technique in particular applications.

Figure 4 shows a test component produced from six layers of 2mm thick mild steel. These layers have been joined using a standard electrical grade solder paste in a reflow process. In this instance the paste was applied manually with no special clamping arrangement and hence the solder layers are slightly uneven in thickness. Initial tests on the solder bonds show them to be reasonably strong although the load carrying ability is highly dependent on the integrity of the interface and the bond area.

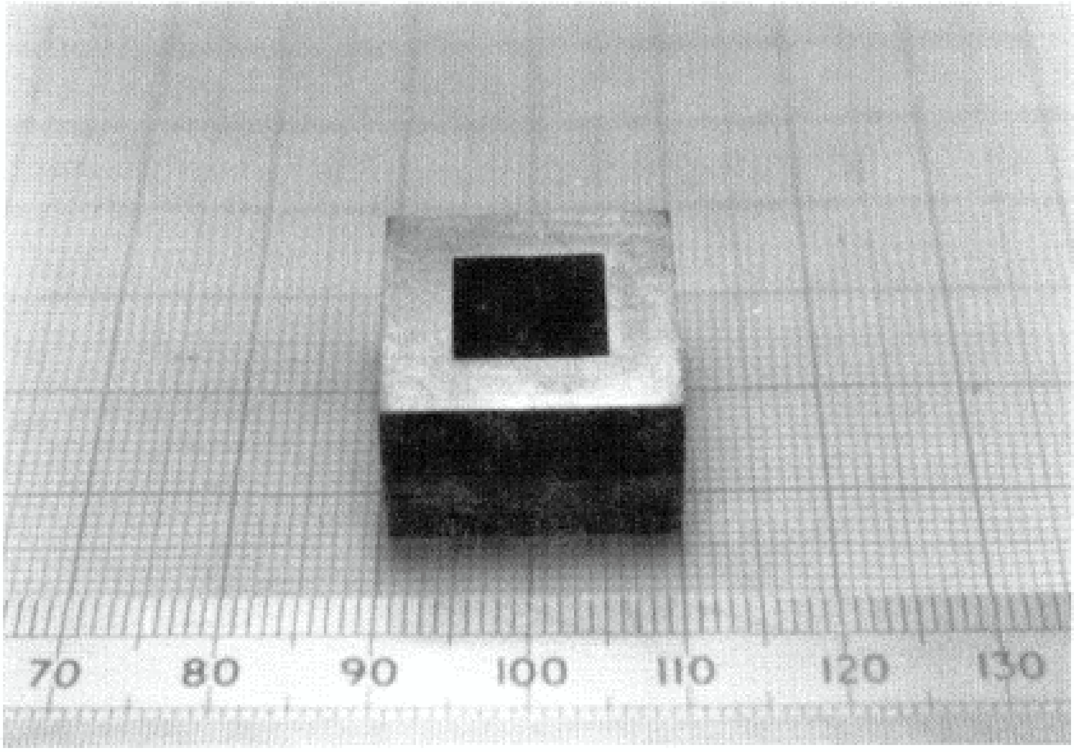

Figure 4 - Soldered Laminate Testpiece

The use of adhesives in engineering and structural applications is a growing area of interest and for certain applications would be viable as a joining technique for metal laminae. As yet only general purpose adhesives have been experimented with and these have produced robust and handleable trial components, Figure 4 shows the component laminae and adhesively bonded structure of a small square based hollow pyramid.

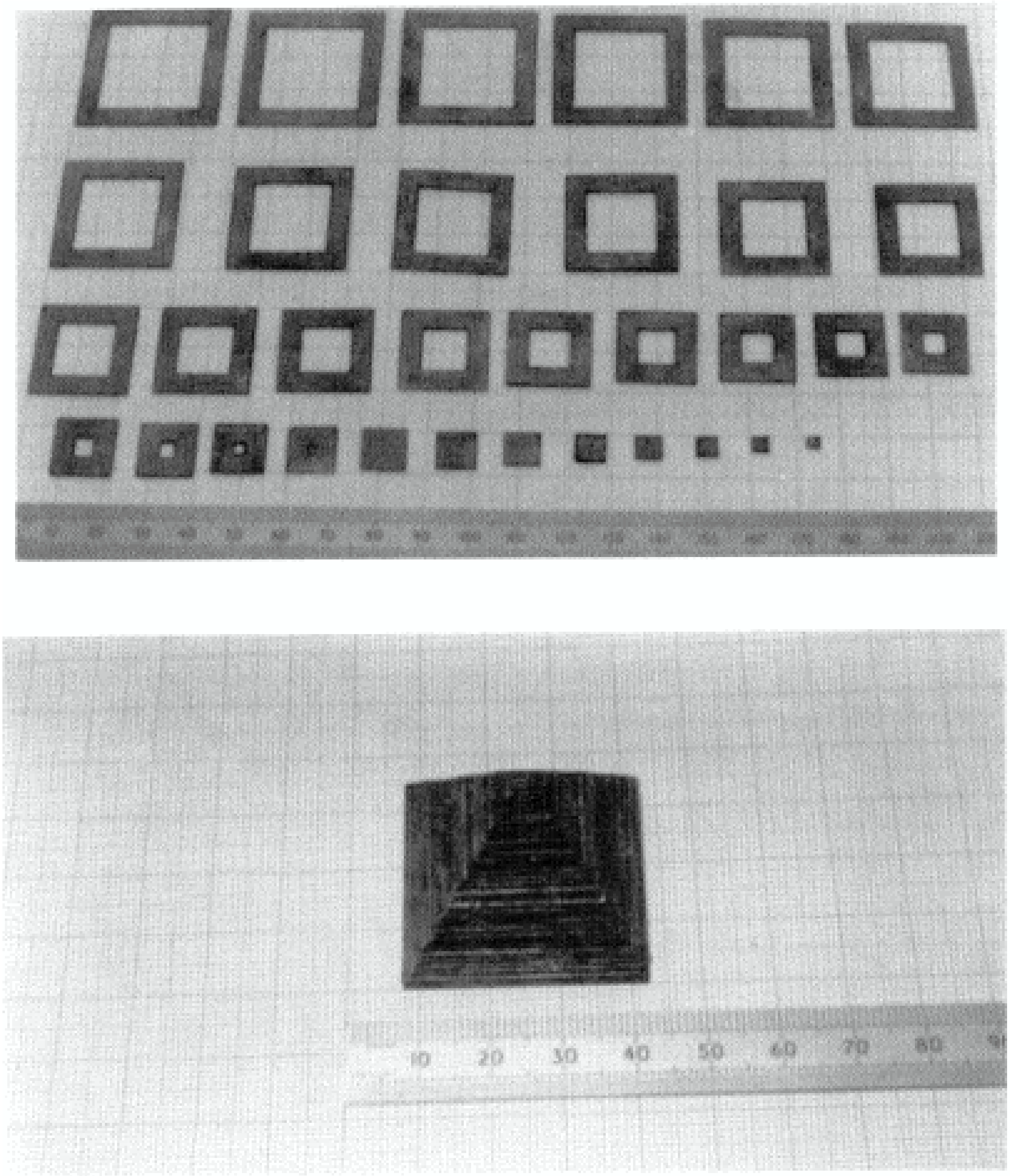

Figure 5 - Individual Laminae and Assembled Pyramid Structure

Laser Forming. Forming trials have been carried out using 1mm and 2mm thick mild steel and 304 grade stainless steel sheet. In order to assess the basic bending behaviour tests were carried out on a 40mm wide strip which was processed from flat to a full 90 degree bend. The strip was passed under the laser beam using an 80mm forward and back double pass action (the 80mm compensates for acceleration and declaration of the XY table.) The deflection against number of double passes was noted in each case. The test was repeated using different values of material thickness, laser power and traverse speed.

An indication of the laser power can be gained from the pulse ratio (which was varied between 20/200 and 20/50) and it was found that the more powerful setting resulted in the 90 degree bend being achieved more quickly. Figure 6 shows the angle of bend against number of passer for various laser pulse settings for 1mm thick stainless steel. Figure 7 shows angle of bend against number of double passes for 2mm thick stainless steel for various traverse feed rates. Figure 8 shows a typical bend produced in 1mm and 2mm thick sheet.

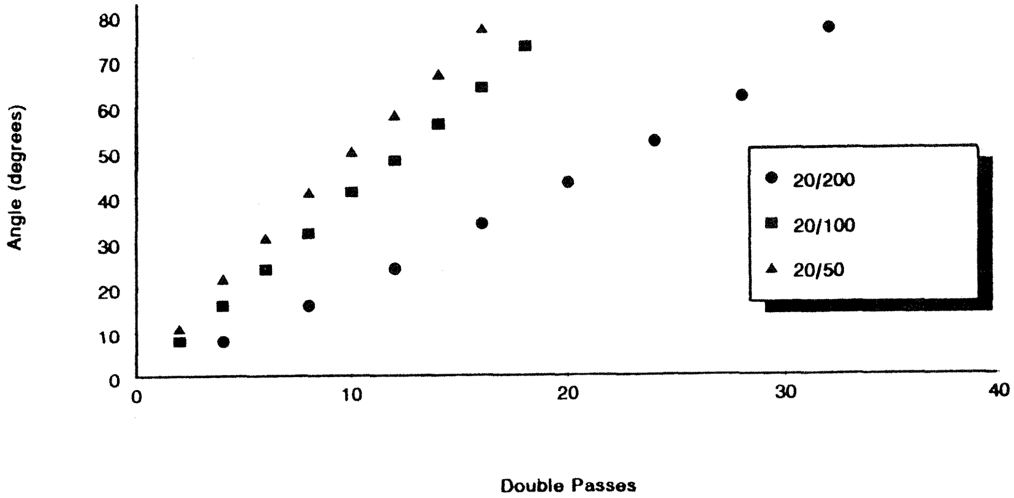

Figure 6 - Angle of Bend Against Number of Double Passes of 1 mm Thick Steel Sheet at Various Laser Pulse Settings

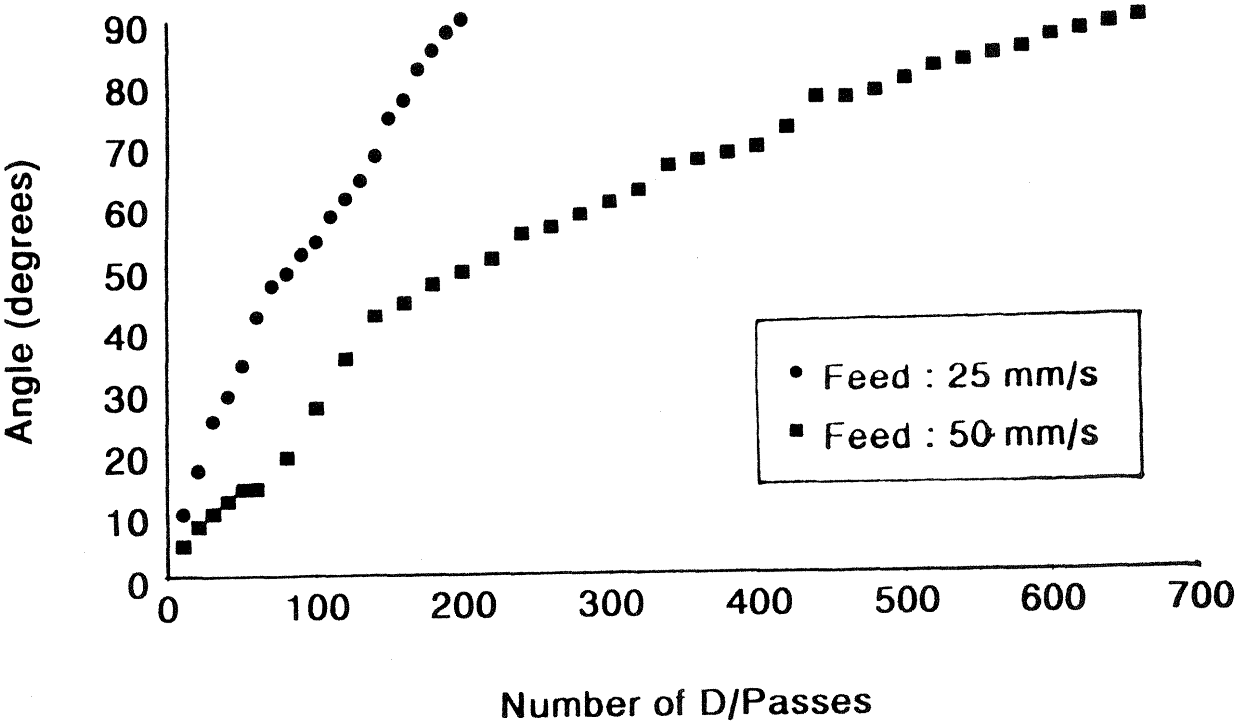

Figure 7 - Angle of Bend Against Number of Double Passes of 2mm Thick Steel Sheet at Various Traverse Feed Rates

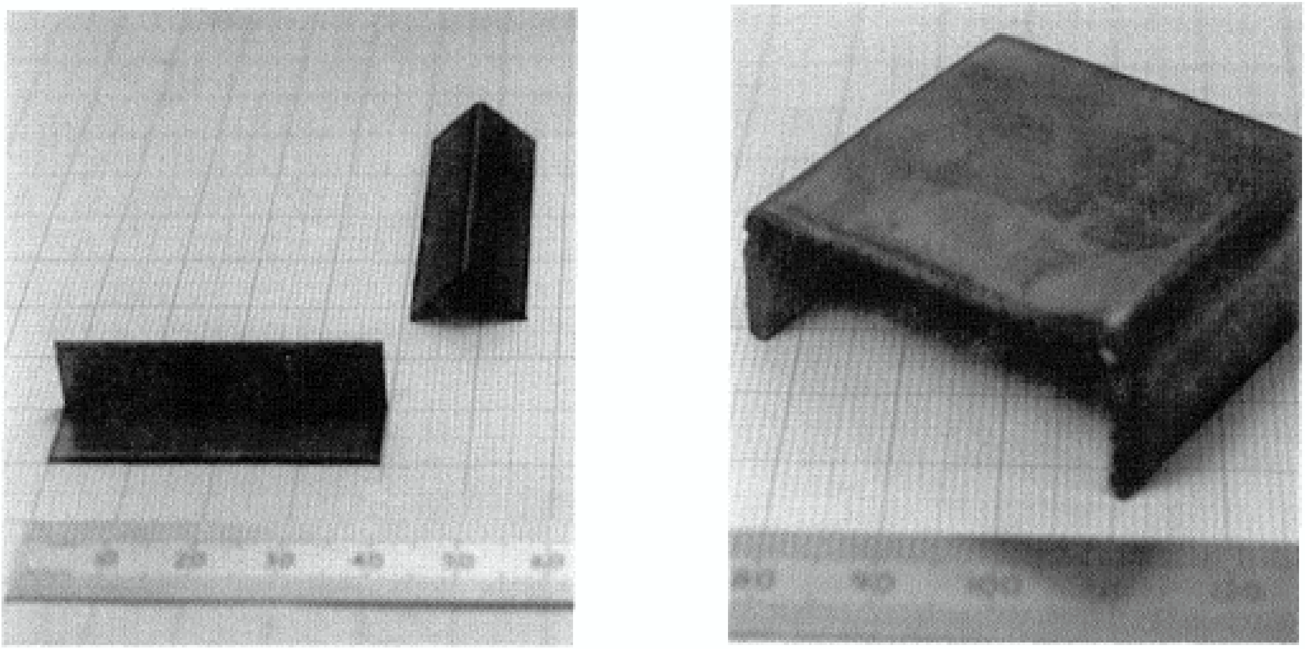

Figure 8 - Typical Bend in 1mm and 2mm Thick Sheet

Most of the current work has concentrated on forming from one side only, it is recognised that in a fully developed working system forming should be possible on both sides of the workpiece. The component shown in Figure 9 was formed from both sides, the flange sections were formed up to 90 degrees from flat pre-cut sheet. The walls were then formed from the other side which then also oriented the flange in the correct position. As more complex parts are produced using this technique it becomes apparent that the order in which particular features are formed may be critical to the success of the processing and this consideration is likely to form a significant part of future work.

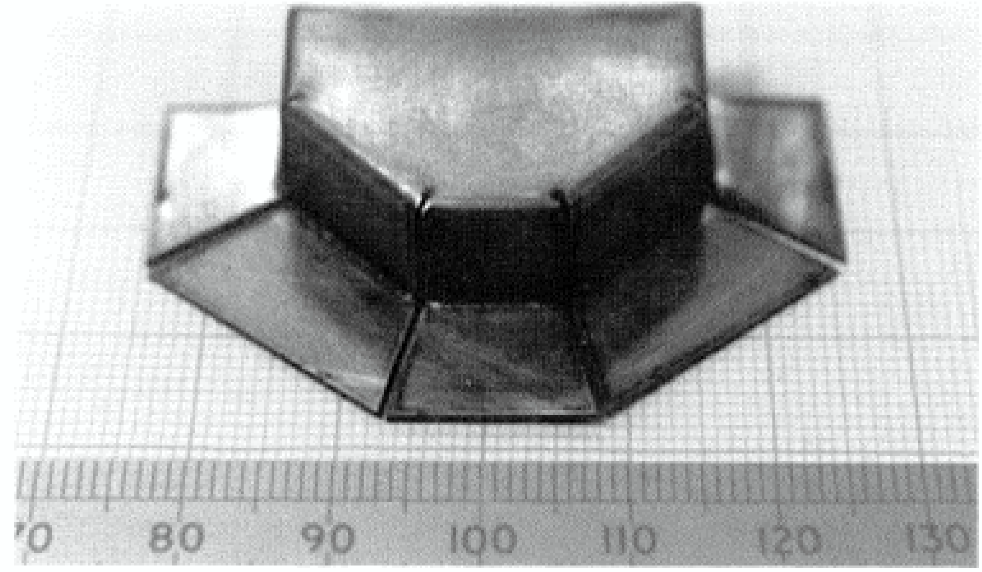

Figure 9 - Laser Forming From Two Sides of the Sheet

As an indication of the potential for systemising the laser forming process, Figure 10 shows the sequential production of a small cube which has been laser cut from sheet, laser formed, and could then be laser welded, it is possible to introduce weld tabs into the geometry to make the welding process more straightforward. The estimated time for the production of the component shown above is five minutes, from raw sheet to welded cube. It is likely that a laser manufacturing system would include a robot manipulator to facilitate the production of more complex geometries.

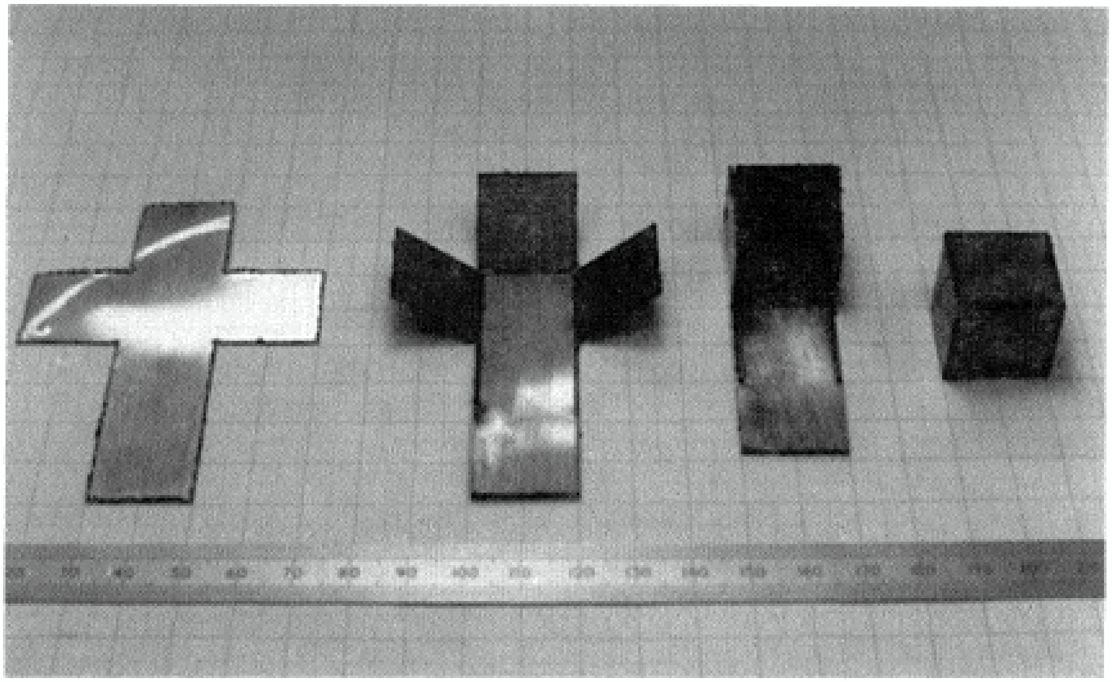

Figure 10 - Sequential Production of a Cube

Further Work

Further areas of investigation are clearly necessary in the work described above before either technique offers a practical production system.

In the case of laminar prototyping, areas of development include the refinement of the methods for joining laminae in order to make this an integral part of the process. Two further areas are currently being investigated namely varying layer thickness so that the build is optimised with respect to the profile geometry, and smoothing the layer steps possibly by using a technique such as laser cladding.

In the area of laser forming an interactive process modelling and empirical test system is being developed.

Results obtained experimentally are being used to gain an understanding of the basic process. It is hoped then to develop a more complete model, compensating for thermal and internal physical stresses to produce the desired geometry. It is hoped that this will allow more precise control of complex curved profiles.

Conclusions

Both laminar prototyping and laser forming show considerable potential and have distinct advantages. For example laminar prototyping offers potential to produce direct metal prototypes in a single process and with no problems in producing features such as overhangs. However further work is required on methods of joining the laminae.

Laser forming offers promise in a number of industries, perhaps the most obvious is sheet metal processing but other avenues as diverse as specialist electronic devices and aids for reconstructive surgery also show considerable potential. Further work is necessary in dealing with non-linear geometry and thick material, but it is anticipated that with the assistance of computer aided process analysis and monitoring a workable system can be developed.

References

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