Laser peen forming of thin sheet ferrous materials

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Abstract

Laser peen forming has been carried out on 0.075mm thick steel samples, using relatively low power Q-switched Nd:YAG lasers at 1064nm, 532nm and 355nm wavelengths. The experiments have been carried out without the usually used tamping layer associated with laser peen forming, which would help to confine the shock wave and direct more of the energy produced by it into the material. An absorptive graphite coating was applied to increase coupling, so that the generation of plasma and shock waves was enhanced. The forming achieved was progressive, producing a bend angle of approximately 1 – 2 degrees per pass. The graphite coating was gradually removed with each pass, and as a result the laser forming effect was limited to the first 15 – 20 passes, after which there was little additional increase in cumulative bend angle.

The results from these experiments have been compared to samples formed using continuous wave laser thermal forming, with similar power settings. The results showed that laser peen forming could take place with a pulsed Nd:YAG laser, and that the laser peen formed samples do not have evidence of heat affected zones or changes to the bulk material, both seen with laser thermal forming. This indicates that the laser peen forming process is largely athermal, as there is very little heat input into the samples except for discoloration of the surface layer due to the plasma which generates the shockwaves.

Keywords: laser peen forming; laser induced shockwaves, micro forming, athermal

1. Introduction

In a number of industry and science sectors, there is a need for precise, remote (non-contact) adjustment of the position and shape of micro-scale structures and components. Through process mechanisms that do not introduce significant thermal input into a material, and which do not damage sensitive material properties and devices. This includes micro adjustment and correction of shape in MEMS devices [1], micro fabrication of disc drive surfaces [2], active alignment of optics in photonic applications, but to name a few potential applications. As the miniaturisation and complexity of micro devices and systems increases, the consideration of localised thermal effects on temperature-sensitive materials and components becomes increasingly a key issue. In the above application areas, and others like them, there is a need for a process which can induce micro-mechanical adjustment without the use of heating mechanisms. For these cases and others like them laser peen forming can be used. It is a relatively new technique and, since short laser pulses are used, forming can take place without significant heat input.

To date, laser based micro adjustment has been approached through the introduction of thermal stresses to induce deformation by established laser forming (LF) mechanisms. Laser forming (LF) is a non-contact technique for the shaping of metallic components. The process works by introducing thermal stresses into a component by irradiating its surface with a laser beam in continuous wave form. This leads to compressive strains or buckling being induced into the component depending upon the laser parameters used. Laser forming can take place by Temperature Gradient Mechanism (TGM), Buckling Mechanism or the Shortening Mechanism [3-8].

As soon as the first pulsed lasers were used, it appeared that shock waves could be easily induced into solids by irradiating the surfaces of solid materials. A plasma is generated when a high power pulsed laser (in the intensity and duration ranges respectively 1-50 GW/cm^2 and 1-50ns) is incident on the surface of a target [9]. From the breakdown of the plasma a shock wave is generated which interacts with the material/substrate causing compressive layers in the upper surface of the material/substrate that leads to the generation of a bend. The effect of the shockwave can be increased using a confining or tamping layer, to direct the shock wave into the material instead of letting it escape (Figure 1). The types of confining/tamping layers which could be used are dielectric material which is transparent to the laser beam, such as water or glass. Since most metals are reflective at these wavelengths, an absorptive layer is also frequently applied to enhance the coupling efficiency.

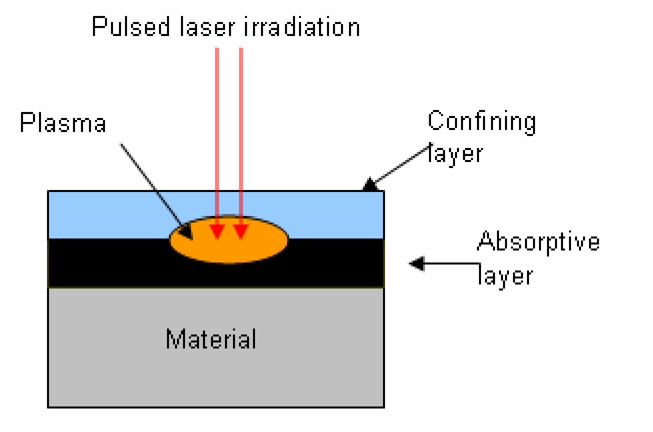

Figure 1 Schematic of laser peen forming showing confining and absorptive layers

2. Experimental

Laser peen forming has been carried out on 0.075mm thick steel samples, using relatively low power Q-switched Nd:YAG lasers at 1064nm, 532nm and 355nm wavelengths. These experiments have been carried out without the usually applied tamping layer associated with laser peen forming, which would help to confine the shock wave. A graphite layer was used as an absorptive layer to increase the generation of plasma, so that shock waves could be formed more easily at the low energy density levels being used. The experiments were carried out with the setup shown in Figure 2, with the laser beam focused in order to generate the highest possible energy density.

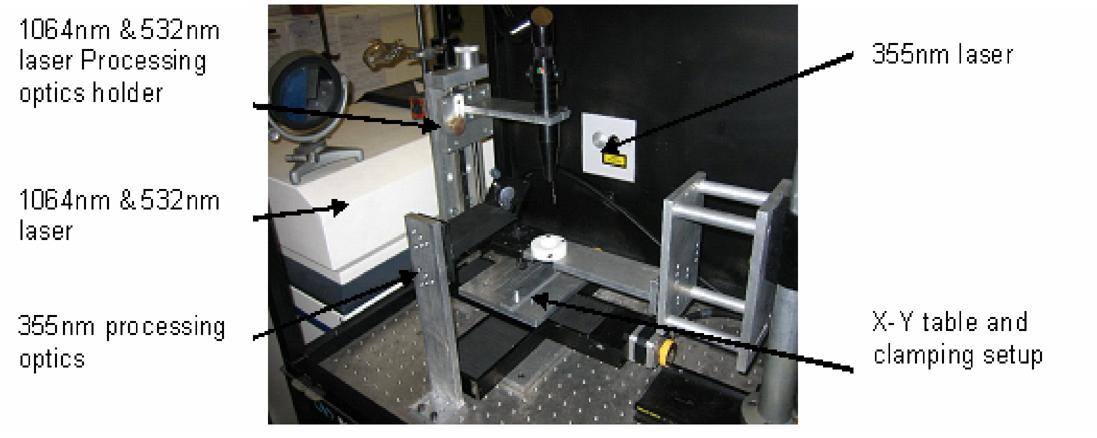

Figure 2 Experimental setup showing the X-Y table and clamping arrangement

The 1064 nm and 532 nm work was carried out using a Paragon 2XL Nd:YAG system with a maximum power of 600 mJ (repetition rate of 1-10 Hz, pulse length 5-10 ns), which produced a spot size of approximately 0.7 mm diameter at 1064nm, and 0.65 mm diameter at 532nm. Both were focused through a 200 mm focal length lens. The 355 nm work was carried out on an Nd:YAG Lynton laser specifically built for operation in the third harmonic with a wavelength of 355nm, a maximum power of 300 mJ (repetition rate of 1-10 Hz and a pulse length of 5 ns). The spot size for this laser was 0.7 mm diameter.

For the three different wavelengths the X-Y table was set to a traverse speed of 5mm/s and the lasers were set to a pulse repetition rate of 10 Hz. The work with the 355 nm wavelength was carried out with an energy density of approximately 5.8 GW/cm^2. The 1064 nm wavelength tests had an energy density of approximately 6.5 GW/cm^2, and the 532 nm wavelength had an energy density of approximately 4.8 GW/cm^2. For the three wavelengths used the power at 10 Hz was set to 180 mJ, so that a direct comparison could be made between each wavelength.

A laser range finder (Figure 3) was used to determine the bend angle produced in each pass on samples exposed under the above conditions. The traverse speed of the X-Y table was set at 5 mm / sec and there was a dwell time of 50 seconds between each laser pass.

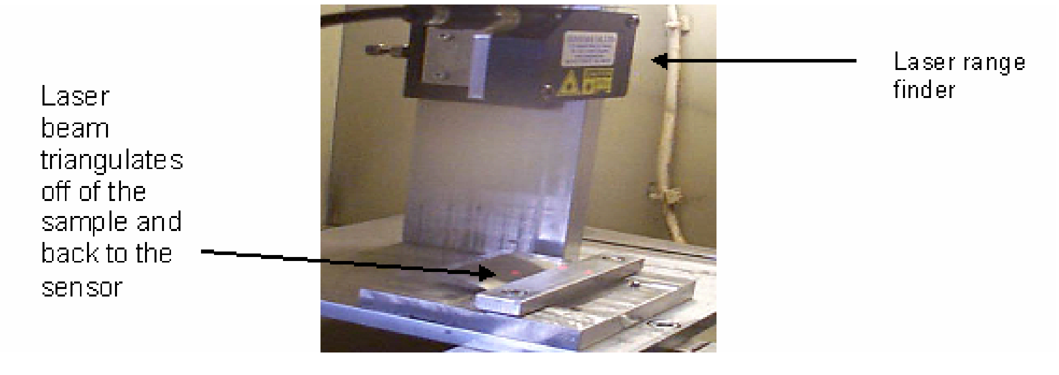

Figure 3 Use of a laser range finder for the measurement of the bend angle.

As with all laser forming, the generation of the bend angle is progressive, being achieved by a number of passes. For each wavelength a series of tests was carried out for 1 - 25 passes to investigate the effect of the number of passes on cumulative bend angle achieved and hence the effect of laser wavelength on laser peen forming.

3. Results & Discussion

3.1 Laser wavelength

Laser peen forming was used to form 0.075mm thick steel samples, with a single layer of graphite sprayed onto them (~0.01mm thick). The results in Figure 5 show the comparison of the cumulative bend angle achieved with the number of passes, for the three selected wavelengths. The same energy setting of 180 mJ had been used at all three wavelengths, so that a direct comparison could be made between each wavelength. The results show that the choice of wavelength on the laser peen forming mechanism has an effect. The 1064nm wavelength sample formed to approximately 18 degrees whereas the 532nm wavelength sample formed to approximately 13 degrees and the 355nm sample formed to approximately 7 degrees. The forming achieved was progressive, producing a bend angle of approximately 1 – 3 degrees per pass. The cumulative bend angle was limited because of the single graphite coating which was used. The cumulative bend angles reached are not the maximum bend angles possible by laser peen forming

After a number of passes with all wavelengths, the graphite layer has begun to be removed, and a smaller change in bend angle can be seen, until eventually the layer is totally removed. This is the case with the work shown in Figure 5; the plateau regions indicate when the coating has been burnt off. In future work, recoating will be tried, to establish the maximum amount of cumulative bend angle possible with laser peen forming under these conditions. It is possible that the effect of coating removal with number of passes masks other processes (such as work hardening and the effect of the change of angle of incident of the laser to the substrate) that may amount too the decrease in the bend angle per pass with number of passes [10].

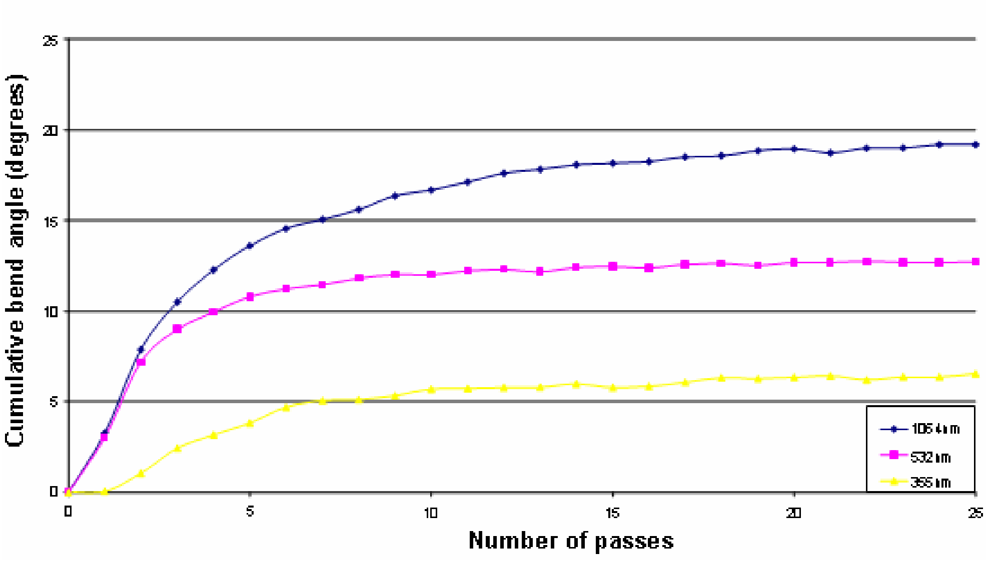

Figure 5 - Comparison of wavelength for laser peen forming at 180mJ, 5mm/s, 10Hz

The variation in the amount of forming which took place with the different wavelengths is due to the magnitude of the shock wave generated, through the breakdown of the plasma. At a wavelength of 1064nm coupling into either the ablative layer or the material is more efficient which leads to the generation of a larger plasma. When the larger plasma breaks down the shockwave generated is more powerful and acts over a larger area. When the shockwave is able to act over a larger area, larger compressive stresses are able to be generated into the upper layers of the material, which leads to larger bend angle being produced. The coupling associated with the 532nm wavelength is less, and subsequently the plasma and shockwave generated area smaller. This leads to smaller compressive stresses being induced in the material, which leads to lesser degree of forming. The same applies with the 355nm wavelength but the coupling is even less at this wavelength.

3.2 Analysis of laser peen forming

From the experiments carried out it was found that samples were able to be formed using the laser shock peen forming method at all the wavelengths tested.

The results from these experiments have also been compared to samples formed using thermal laser forming with the temperature gradient mechanism, to investigate the differences between thermal laser forming and laser peen forming. The main aim of this was to see if there was a heat affected zone in the laser peen formed samples, and if so to compare it to a thermally formed sample. The results for the thermally formed sample seen in Figure 6, showed the large thermal input into the material and the heat affected zone. This would be disadvantageous in highly heat treated alloys in specialist applications such as aerospace. The laser shock peen formed sample shown in Figure 7, showed no sign of heat input and no change to the materials structure. This indicates that the laser peen forming process is largely athermal, as there is very little heat input into the samples.

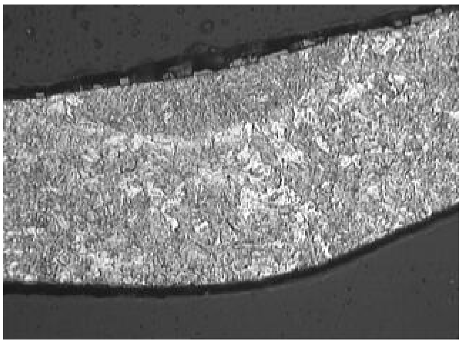

Figure 6 A laser thermally formed sample (x 600)

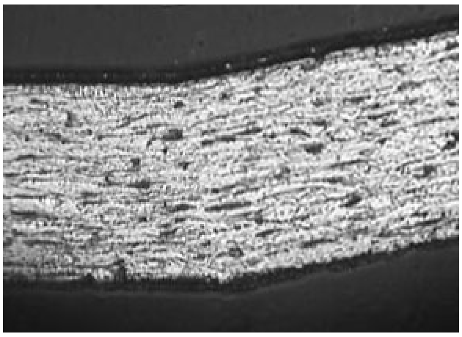

Figure 7 A laser shock peen formed sample (x 600)

4. Conclusion

Laser shock peen forming has been successfully used to form 0.075mm thick steel and a number of conclusions from the work carried out, these include: -

- The ability to form samples with a pulsed Nd:YAG laser, at the variety of wavelengths tested which include 1064nm, 532nm and 355nm.

- The wavelength used in laser peen forming has been found to have an effect on the bend angle produced. With a wavelength of 1064nm producing larger cumulative bend angles than the 532nm and 355nm wavelengths.
- The process has been found to have the ability to form samples without inducing the large heat affect zones or changes to the bulk material, which is seen with laser thermal forming. This indicates that the process is largely athermal.
- It has been found that laser peen forming can be used without the usually associated tamping layer, which would be used to confine the shockwave to the surface of the material.
- The laser peen forming mechanism can be used to form material to relatively substantial angles on 0.075mm thick steel.

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