Shock Peening of engineering ceramics using contact-less energy beams

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Research Background

Laser Shot (Shock) Peening is a comparable process to the conventional shot peening technique applied on various types of metal surfaces. Commercial advantages offered by the laser systems such as flexibility, deep penetration (precise control of the thermal input), shorter process times, high speeds, accuracy and aesthetics are attractive in comparison with the conventional peening technique. Laser peening in the recent years has developed and proven its success with steels, aluminium and titanium surfaces, although, minimal research has been conducted on laser shock peening and conventional shot peening of engineering ceramics [2, 4, 5]. The aim of this investigation is to begin the process of addressing the gap in knowledge by applying industrial lasers to hot pressed silicon nitride (HP Si_3N_4) in particular as a typical engineering ceramic. This investigation is highlighted on the feasibility of shock peening Si_3N_4 using contact-less energy beams such as industrial lasers and investigates a change in the significant mechanical property; fracture toughness (K_{1c}) of the Si_3N_4 ceramics. A 2 Kw pulsed Nd: YAG laser is used assisted by an industrial robot to conduct experimentation on the HP Si_3N_4 ceramics.

1.0: Introduction

Applications of ceramics have been limited due to their crack sensitivity and low fracture toughness (K_{1c}), however, the use of ceramics have advanced over the years. They are now considered as the new age material used to manufacture components for the aerospace, automotive and military sectors. Engineering ceramics offer exceptional mechanical properties, which allows them to replace the more conventional materials currently used for high demanding applications. The mechanical property under investigation was fracture toughness (K_{1c}), since it is a very important property of any material and especially ceramics in particular due to their brittle nature. Ceramics in comparison with metal/ alloys have a low K_{1c}, hence it would be an advantage if the K_{1c} of ceramics could be improved using a laser shock peening technique. This can open avenues for ceramics to be applicable to high demanding applications where metals/ alloys fail due to their low thermal resistivity, co- efficient of friction, wear rate and hardness in comparison with ceramics.

In all cases a comparison was made with the characteristics of the conventional shot peening process to assess the feasibility of surface treating engineering ceramics by the aid of energy beams, to identify if a similar outcome is obtained to that of the conventional mechanical technique [1].

2.0: Comparison of Systems

2.1: Constraints with Conventional Shot Peening

- Changes in the surface topography
- Deformation of the shots
- Change of shot size requires machine set up
- Shot diameter is only suitable for a specific type of nozzle
- Recollection of shots
- Shot peening control and processing intensity
- Distortion

2.2: Rational for implementing contact-less shock peening

- Penetrating depth of residual stress induced into the material
- Improvement with surface roughness
- No tool change require
- No recollection of the fired shot
- Availability of superior motion system and freedom of movement that aids programming of complex shapes and geometries.
- Feasibility for cooling the work-piece

2.3: Cost Summary

Cost of laser peening is high in comparison with the conventional shot peening systems. However, laser peening is simply a superior process with controllable parameters offering shorter process times. A small/medium size, brand new shot peening machine could cost up to 30 K (GBP). In comparison, an average Nd: YAG or a CO_2 high power laser system (brand new) would cost up to 200 K to 250 K (GBP).

Laser Peening is an independent process, which means that it is performed after the component has been manufactured. Most small medium size manufacturers do not invest on laser peening systems for carrying out such a surface treatment. This is simply because the laser systems are far too expensive to run and maintain just for the purpose of a peening application.

The charges made by the job shops are purely dependant on the component size, shape, geometry, weight quantity, ablative layer, area of peening (number of laser spots) and the customer specification. Although, a typical hourly rate charged by a laser job shop for shot peening a component such as large tubular welded heat exchanger can be charged up to 75 (GBP) per hour. This included labour, machine set up and variable costs such as electricity wear and tear of the equipment. The number of hours spent on one particular job is again purely dependant on the features of the component. In comparison with laser shock peening rates, the typical charges given for the mechanical shot peening process was quoted up to 70 (GBP) which includes the machine set up time. The reason for the cost of laser shock peening being higher than that of the mechanical shot peening is due to the involved machine programming skills required by the operator and also due to laser machinery comprising of more complexity during operation.

3.0: Experimental Procedures

Sample size of 50mm x10mm x10 mm HP Si_3N_4 ceramics were used for the experiments which were coloured with a thin layer of black ink to increase the laser absorption. A 2 Kw pulsed Nd: YAG (Niodinium, Yitrium, Aluminium Garnet) industrial laser was employed with a 1.06 μm wavelength, assisted by a KC-25 Kuka industrial robot. To imitate the shot peening process, it is required that a top hat beam was used so the output energy of the laser beam was distributed evenly on the surface of the ceramic.

The Nd: YAG laser was comparable with the current industrial systems used for laser shock peening/ hardening. A 3mm diameter spot was used for duration of 10 ms with power densities ranging from 11 Kw/mm^2 to 16 Kw/mm^2. Argon was used as a processing gas at pressures of 1 bar to minimise the effect of surface oxidation or a possible change in the ceramics composition.

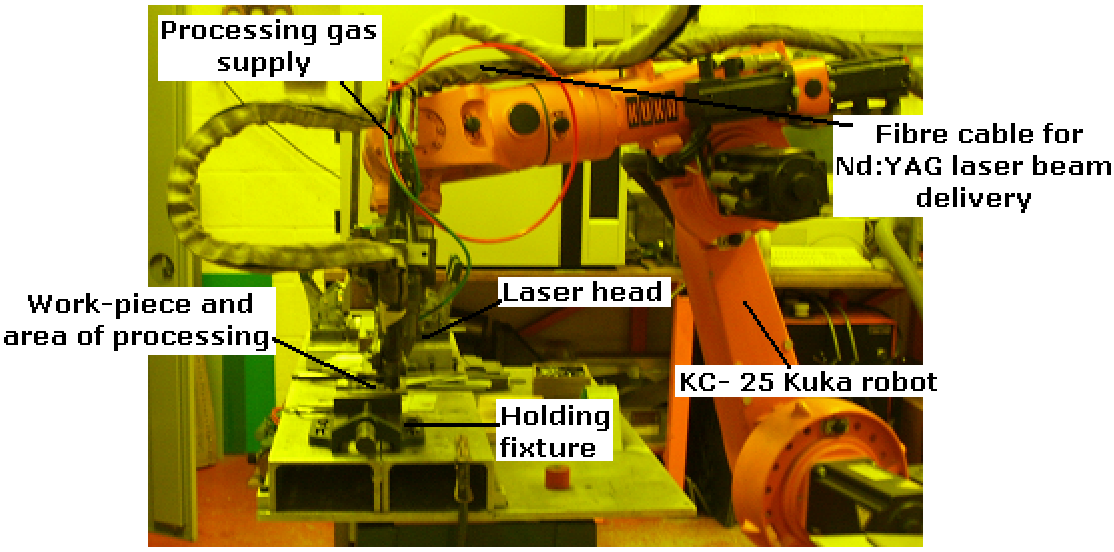

Figure 1: Nd:YAG Laser delivered by a fibre cable mounted on the KC-25 Kuka robot during laser peening of Si_3N_4, placed on a holding fixture.

4.0: Summary of Results

- Minimal effect on the ceramic was found below power densities of 11 Kw/mm^2.

- Thermal shocking resulted in the material fracturing when power densities up to 16 Kw/mm^2 were induced. Power densities below this range displayed an absence of cracking on the ceramic surface.

- K_{1c} of the ceramics was enhance by 19 % and was calculated as 7.12 MPa $\sqrt{m}$. This was due to the softening of the top layer of the ceramic which reduced the hardness leading to a significant increase in the ceramics K_{1c}.

- Over 35 % decrease in the materials surface hardness was found which resulted in boosting the ceramics K_{1c}. This indicated that the effect of laser shock peening of metals/alloys is different to that of the engineering ceramics.

- Surface roughness of the Nd:YAG laser peening was enhanced from 0.07 µm (untreated surface) to 0.049 µm after the shock peening treatment which shows a 0.23 µm enhancement in the surface roughness after the shock peening treatment.

5.0: Summery

There are several constraints with the conventional shot peening process which open up avenues for research work to be considered in this area. In order to gain any benefits from the process, it is vital that the material surface yields mechanically and the process of tensile stress is reversed so compression can be induced into the material. This is not common with ceramics as they do not yield and plastically deform readily.

Existing constraints within the conventional shot peening process could be counteracted if non-contact processes such as laser peening is implemented particularly with ceramics. The cost of the laser systems is much higher in comparison with the conventional shot peening process. However, laser peening is much superior to the conventional shot peening due to the depth of the compressive residual stress obtainable [2, 3, 4, 6]. Other reasons as previously discussed such as faster processing time, flexibility with treating components of complex geometry and overcoming the constraints existing by mechanical shot peening will attract large manufacturing companies to implement such a system. However, SME's (Small Medium size Enterprises) will most likely revert to sub-contract the process to job shops.

Laser peening at the moment is only performed according to the customer demand and component specifications, typically when the product demands deep induced residual stress (automotive gears) for example. Engineers and designers have to make a choice between processing cost and quality of treatment when choosing either laser peening or the conventional shot peening process.

Processes such as laser peening have proved to be successful surface treatment methods for metals and also generate further benefits compared to the more conventional mechanical shot peening technique. This investigation proves a way forward with laser shock peening of ceramics from the view point of gaining the better from brittle materials such as ceramics. Further work is ongoing with regards to the current findings and the behaviour of the ceramics during pulsed laser beam interaction.

Further results presenting the justification of the current finding (in depth), along with the laser beam material interaction during the laser shock peening treatment of Si_3N_4 ceramics are justified in the technical paper.

6.0: References

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This research was conducted by Pratik Shukla working as a research student for the degree of MSc by research at the Centre for Advance Joining (Coventry University, United Kingdom), under the supervision of Dr Colin Page, 2006- 2009.