Using an Ytterbium fiber laser to fracture splitting of compacted graphite iron bearing caps

Rudimar Rivas1, Milton Sérgio Fernandes de Lima2, Nicolau André Silveira Rodrigues3, Samoel Mirachi4 and José Claudio Macedo Cardoso4

1) Instituto de Estudos Avançados – Rodovia Ramos, km 5 – S. José dos Campos – SP – rravie@iaeav.cta.br
2) Tupy Fundições Ltda. – R. Alano Schmidt, 4300 – Joaína – SC

Abstract
This paper presents the results of the assessment of fracturing splitting of compacted graphite iron (CGHS450) bearing caps assisted by Yb fiber laser. Notch drilling parameters were evaluated for different values of laser power and pulse repetition rates for normal and 45° inclination. The best conditions were established when using O2 as assist gas, 500 W of laser power, 1 ms pulse width and 45° inclination. Bearing caps prototypes were fractured at the best conditions using a hydraulic expanding mandrel device. Deformation of bearing caps were evaluated by measuring roundness and circularity of fractured bearing caps. When compared with other notching methods, engraving, mechanical broaching and Nd-YAG lasers, the results obtained with Yb fiber presents the smallest deformation.

Introduction
The fracturing splitting method is been increasingly used for manufacturing of automobile engine components like connecting rods. The process consists on engraving two opposed notches into the inner side of the rod body, connecting rod big end, and the cap end rod are split by mechanical pressure due to high concentration of stress on the notches. This innovative method produces reduction costs eliminating many later machining tasks necessary on the conventional method wherein connecting rods are fabricated with separate parts [1]. This technology has been also applied for the crank shaft bearing caps of the engine blocks [3]. The experimental results obtained on fracturing connecting rods indicated that the adequate notch depth is 0.4 - 0.7 mm and that the bottom notch radius must be smaller than 0.4 mm [4]. Although the notches can be engraved by broaching, the best results are obtained using lasers with good beam quality.

So, the aim of this work is to investigate the use of a modern Ytterbium fiber laser to engrave thin notches on bearing caps made of CGI. Besides the exceptional laser beam quality, the fiber laser is very compact and free of maintenance, which is a very important feature on industrial application of lasers.

Experimental setup
The experiments were conducted on machined samples blocks of CGHS450 using a 2 kW Ytterbium fiber laser (IPG Photonics). The fiber laser can be operated on CW or modulated mode at repetition rates up to 5 kHz. The 100 µm core diameter output fiber was connected to an optical head (OpgSband 1601060), with focal distance of the lens adjustable from 155 mm to 165 mm. With this optical head, the laser beam has a b.p.p. (beam parameter product) of 4.2 mm.mrad and the spot size radius (86%) on focus position is 45 µm. A cutting head with 1.0 mm nozzle, attached to the optical head, was pressurized with 10 bar of O2 or N2.

The distance of the cutting head nozzle and sample surface was 1 mm.

The focusing optical head was set perpendicular or at 450 to the top surface of the CGI samples, which were fixed on a CNC driven XYZ table as shown in Fig. 3. The translation speed of the table is limited to 8 mm/s.

The study of the process parameters was first carried out focusing the laser beam on the surface of rectangular blocks 20 mm thick.

Afterwards, we used the best results obtained to engrave the notches on the internal surface of 120 mm x 120 mm bearing caps prototypes with internal diameter of 80 mm and wall thickness of 22 mm.

The bearing caps prototypes were mechanically fractured with a hydraulic expanding mandrel device shown in Fig. 1. The expanding mandrel is actuated by a cylinder piston of 100 mm in diameter. In all fracturing tests, the pressure on the cylinder piston was fixed on 200 bar and the mandrel travel was 1mm.

Results and discussion
Generally, blind cut or notches on surface materials are obtained using pulsed lasers with intensity greater than 106 W/cm². Uninterrupted notch is produced by continually superimposing laser pulses over a moving sample. With a 45 µm radius spot size and considering the fiber laser operating with 1 µs pulses and 1 kW of power, the estimated hole depth is 1.3 mm, which is larger than the 0.5-0.7 mm reported in literature for fracturing glass [1,4].

The hole depth can be controlled both by changing the laser power or the pulse duration. However, the pulse duration affect the diameter of the holes and the way the material is removed from the hole: melt or vapour ejection [7]. With low power and long pulses, most of the material is melt ejected and the hole diameter is proportional to the thermal diffusion length, that is defined by:

\[ L_0 = 2a \left( \frac{\tau}{c} \right)^{1/2} \]

where \( a = 1.1 \times 10^{-6} \) m²/s is the CGI thermal diffusivity coefficient. For laser pulse duration \( \tau = 1 \) ms, the CGI thermal diffusion length is \( L_0 = 2.3 \) mm. The influence of pulse duration is clearly shown in Fig. 3, where the holes were drilled using 400 W of laser power with two pulse lengths of 1 ms and 5 ms. A great quantity of material is removed by melt ejection, as it can be observed in the top view of Fig. 3. Holes diameters of 230 µm and 380 µm for 1 ms and 5 ms pulses, respectively, were measured after grinding the sample (bottom view of the Fig. 3).

Since laser beam diameter on focus position is only 90 µm, these results indicate that, on our experimental conditions, the hole dimensions are mainly defined by the thermal diffusion length. As the fracturing process improves with smaller notch width, the pulse length was fixed on 1 ms ever since.

Lasers with better beam quality have larger depth of focus and thus, the hole depth is less dependent on the focus position during the displacement of the sample. In order to estimate the depth of focus, the experiments were done with two different angular positions of the optical head: at 0° and 45°. In order to maintain constant the laser intensity, the power of the laser was 200 W for 0° and 300 W for 45°.

The results are depicted in Fig. 5, where Af is the distance between surface sample and focus position. At perpendicular (90°) position, the depth of focus (the distance in which beam diameter does not vary more than 5%) is only \( \tau = 0.16 \) mm. When the optical head is on 45° position, the hole depth (or beam radius) is almost constant in a range of \( \pm 0.5 \) mm. This condition allows obtaining very regular and reproducible notches due to larger tolerance on focus position. A larger dimension on the travel direction allows increasing process speed which depends on pulse superposition. Moreover, this angular position allows the gas jet to eject easier the melt and vapor retainted inside the notch [5].

At this angular position, we carried out several experiments varying the laser power from 300 W up to 1500 W and the process speed from 1 mm/s to 4 mm/s. The temporal length and repetition rate of the pulses were 1 ms and 20 Hz, respectively. Both \( N_2 \) and \( O_2 \) were used with 10 bar pressure. Typical experimental results for two values of laser power are shown in Fig. 7. A great fraction of the melt remains inside the notch, that it a very different situation observed with single pulses, where almost the whole melt was ejected from the hole inside. This indicates that the melt is flushed on to the previously drilled notch. The fraction of imprisoned melt increases when the laser power increases and when the process speeds down, probably because the drilled holes are more superposed. With 02 this fraction is slightly decreased due to the oxidation reaction.

Contrary to the expected, no significant differences were observed on dimensions of notches when using \( N_2 \) or \( O_2 \), except that the dross on top surface is removed without difficulty for the latter.

The measured kerf varied from 180 µm to 230 µm when the power was increased from 300 W to 1500 W in whole range of process speed.

The measured notch depth, as function of the laser power, and for the interval of process speed from 1mm/s to 4 mm/s, is nearly the same both for \( O_2 \) and \( N_2 \) as shown in Fig. 8.

The results obtained at higher process speeds seem more adequate to use for fracturing splitting, since less material remains inside the notches. In this way, fracturing splitting of bearing caps prototypes was tested with \( O_2 \) process speed of 4 mm/s and laser power of 500 W to 1500 W.

All the tests were successful, and a typical example of a fractured bearing cap using 500 W of laser power is presented in Fig. 9.

The surface near the notch region was painted with blue ink before cracking allowing visualizing a very regular fractured notch (top view of Fig. 8), with an average depth of 0.5 mm. The fracturing follows the line with a deviation smaller than 1 mm. The deformation of the bearing cap was estimated by measuring the roundness and circularity before and after the fracturing. The deformation results obtained with the Yb fiber laser working with 500 W of power were compared to three other methods ofscribing the notches.

1) Mechanical broaching, with notch depth of 0.66 mm.
2) Nd-YAG laser, FBIA F1100C10, nominal power of 100 W, with notch depth of 0.4 mm.
3) Nd-YAG laser, LASAG 246, nominal power of 250 W, with notch depth of 2 mm.

Fig. 10 presents the roundness and circularity measurements obtained for all methods, which were performed on the same prototypes with 200 bar of pressure on the hydraulic mandrel device. On the top of the graphics is also shown a notch microscopic view for each one of the methods.

However the notch depth produced by the mechanical broaching is not comparable to those obtained with the lasers, the deformation after fracturing is much larger, and indicating that the thermal stress produced with the lasers contributes positively on fracturing process.

Conclusions
The results obtained in this work showed that the Yb fiber laser can engrave the notches for fracturing splitting with adequate dimensions using only 500 W of power. In comparison with other methods, the best results for fracturing deformation were obtained when using the Yb fiber laser.

* The authors are grateful for the financial support of: FINEP and Tupy Fundições Ltda. and DM Promau for the fracture tests.