EFFECT OF PRE-FABRICATED KERF SIZE ON THE DIRECTIONAL PROPAGATION AND SURFACE QUALITY OF CRACKS DURING CONNECTING ROD FRACTURE SPLITTING

ẢNH HƯỞNG CỦA KÍCH THƯỚC HÌNH HỌC RÃNH KHÍA TIỀN CHẾ TỚI SỰ LAN TRUYỀN ĐỊNH HƯỚNG VÀ CHẤT LƯỢNG BỀ MẶT CỦA VẾT NỨT TRONG NGUYÊN CÔNG CẮT ĐÔI ĐẦU TO TAY BIÊN

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ABSTRACT

3D Fracture Splitting (FS) is a new technology used as an alternative to the traditional machining process of splitting a connecting rod's big-end in an automotive engine. The 3D concave-convex matching surface after fracture replaces the 2D planar mating surface of the traditional method. Through this 3D mating surface, the two halves of the connecting rod's big-end can be easily and accurately positioned in the subsequent assembly process. This article focuses on the operation of pre-fabricating kerf by using laser cutting and the directional fracture splitting process of connecting rods made of A356.0 cast aluminum alloy, with deep research on the influence of the geometric dimensions of the pre-fabricated kerf on 3D-fractured surface quality (e.g., the occurrence of mechanical defects such as plastic deformation, metal defects, branching, etc.). Experimental results show that, for medium-sized connecting rods made of A356.0 cast aluminum alloy, a pre-fabricated kerf size of width l = 0.3mm and depth d = 0.5mm offers a reasonable surface quality and good appearance.

Keywords: *Fracture splitting; connecting rod; big-end; laser cutting; A356.0.*

TÓM TẮT

Chặt gãy định hướng 3 chiều (3D Fracture Splitting) là một nguyên công mới được sử dụng để thay thế cho nguyên công cắt đôi đầu to bằng các phương pháp gia công truyền thống, trong quá trình gia công chi tiết tay biên động cơ ô tô. Bề mặt tiếp xúc theo biên dạng lồi lõm 3 chiều sau chặt gãy sẽ thay thế cho bề mặt tiếp xúc theo biên dạng phẳng 2D của phương pháp truyền thống. Nhờ bề mặt 3 chiều này, hai nửa đầu to tay biên dễ dàng được định vị chính xác trong quá trình lắp ghép tiếp theo. Bài báo này tập trung vào nguyên công tạo rãnh khía tiền chế bằng laze và nguyên công chặt gãy đầu to tay biên làm bằng vật liệu hợp kim nhôm đúc A356.0, trong đó đi sâu vào nghiên cứu ảnh hưởng của thông số kích thước hình học của rãnh khía tiền chế đến chất lượng bề mặt vết nứt (ví dụ khả năng xuất hiện các khuyết tật cơ học như biến dạng dẻo, khuyết kim loại, phân nhánh,...). Kết quả thực nghiệm cho thấy, khi gia công tay biên cỡ vừa làm bằng vật liệu hợp kim nhôm đúc (A356.0), với kích thước rãnh khía tiền chế, bề rộng l = 0,3mm và chiều sâu d = 0,5mm sẽ tạo ra trạng thái vết nứt và chất lượng bề mặt đạt yêu cầu.

Từ khóa: *Chặt gãy định hướng; tay biên; đầu to tay biên, gia công laze; A356.0.*

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1. INTRODUCTION

A connecting rod is a crucial component in internal combustion engines, functioning as a lever to connect and transfer the piston's reciprocating motion to the rotational motion of the crankshaft and flywheel [1]. Fundamentally, a connecting rod consists of four primary components and additional subcomponents as illustrated in Figure 1. These primary components include: the small-end (connected to the piston head), the connecting rod body, the big-end (connected to the crankshaft), and the connecting rod cap (for split connecting rods, commonly used in most internal combustion engines) [2]. The machining and assembly of the big-end and cap play a critical role in precisely positioning and dimensioning these two components relative to the crankshaft, significantly impacting engine efficiency and lifespan.

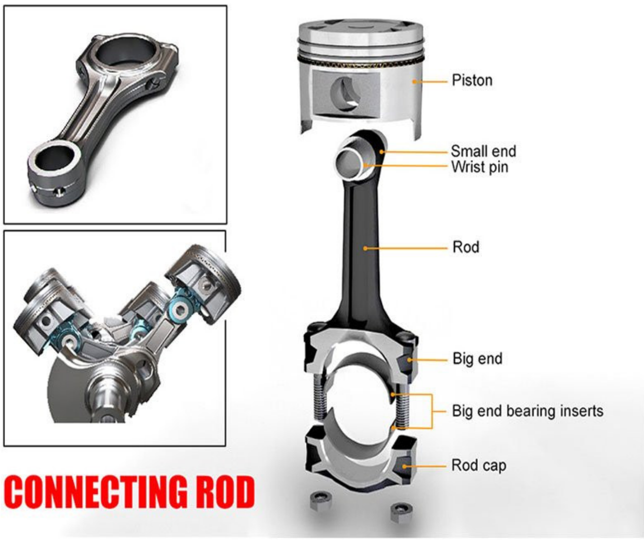

Figure 1. A typical structure of a connecting rod [2]

Traditional manufacturing processes for splitting big-end connecting rods involve contour cutting, which often leads to difficulties in achieving precise mating surfaces [3]. Subsequent finishing operations are necessary to ensure the required size and roundness of the internal cylindrical surface. The directional fracture splitting offers several advantages, including improved roundness of the internal cylindrical surface, reduced equipment and tooling costs by 25%, lower energy consumption by 40%, and a 30% reduction in processing time [4].

Basically, the directional fracture method for splitting the big-end of connecting rod components in the automotive manufacturing process is illustrated in Figure 2. The core of the directional fracture process includes: creating the pre-fabricated notches (stress concentration area) by laser and fracturing using a hydraulic press. The result is a 3D concave-convex mating surface on both halves of the big-end and cap, as shown in Figure 3. This 3D surface replaces the traditional flat surface, ensuring accurate positioning of the two halves for subsequent machining and assembly.

Figure 2. A directional fracture-based manufacturing process for connecting rods

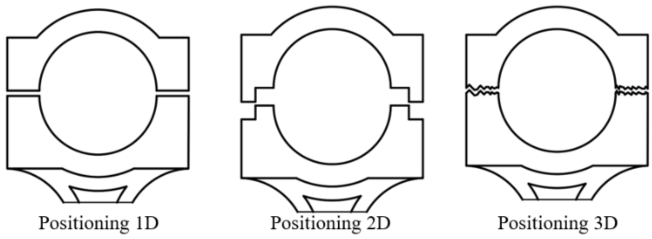

Figure 3. Various type of mating surfaces

Studies on directional fracture methods have shown that the pre-machining laser notching process significantly impacts the surface quality and defects that occur during the fracture process [5 - 8]. S. Fukuda et al. investigated the influence of some factors of S53CV-FS steel material on directional fracture machining [5]. L. Zheng and colleagues studied the parameters for the pulsed Nd:YAG laser engraving process of C70S6 steel for connecting rod fracturing [6]. S. Kou and colleagues conducted a study on the influence of auxiliary gas in laser pulses the optimal machining of pre-fabricated notch by fracture method [7]. Z. Shi et al. analyzed surface defects on the spliting surface based on finite element analysis [8].

Currently, there is no specific research in Vietnam on directional fracture methods. Therefore, in this paper, the influence of pre-machined notch geometry on the directional propagation and surface quality of cracks will be investigated. Experiments were conducted on medium-sized connecting rods made of A356.0 cast aluminum alloy material. The operation of pre-machining notch was carried out by laser engraving, and the fracture process was performed on a hydraulic press. Defects of 3D convex-concave surfaces after machining were evaluated with various geometric parameters of pre-machined laser notches. The results of this article provide a significant basis for selecting appropriate geometric parameters in pre-machining notches for A356.0 aluminum alloy connecting rod.

2. MATERIALS AND METHODS

2.1. Materials

The selected A356.0 connecting rod sample, widely used in mechanical production due to its good load-bearing capacity and fatigue resistance, used in air compressor of Fengli factory. It has a configuration as shown in Figure 4. The chemical compositions and mechanical properties of A356.0 aluminum alloy are as shown in Table 1 and Table 2 [9 - 11].

Figure 4. Sample connecting rod in experiment

Table 1. Chemical compositions of A356.0 aluminum alloy (wt%)

Al	Si	Fe	Cu	Mn	Mg	Zn	Ti	Other
91.1 - 92.3	6.5 - 7.5	0.2	0.2	0.1	0.25 - 0.45	0.1	0.2	0.15

2.2. Experimental methods

2.2.1. Forming pre-fabricated kerf

Pre-machining of starting notch (kerf) is a crucial process in the formation and propagation of cracks. The notch acts as a stress concentrator, initiating crack formation at this location and propagating through the entire thickness of the big-end. The notch is also a prerequisite to satisfy the structural failure conditions of this method. The location of the notch determines the exact position of the convex-concave surface after machining. There are two methods for pre-machining notches, including broaching (traditional machining method) and laser engraving (advanced machining method). Currently, with the development and widespread use of advanced manufacturing processes, laser-based machining method is widely used in the production of connecting rod due to its advantages such as non-contact processing, good surface quality, high machining accuracy and automation capabilities. In this experiment, the laser engraving was adopted for notching. The machine used in this experiment is Laser Namson Power Mark Eco F series – the fiber laser engraving machine.

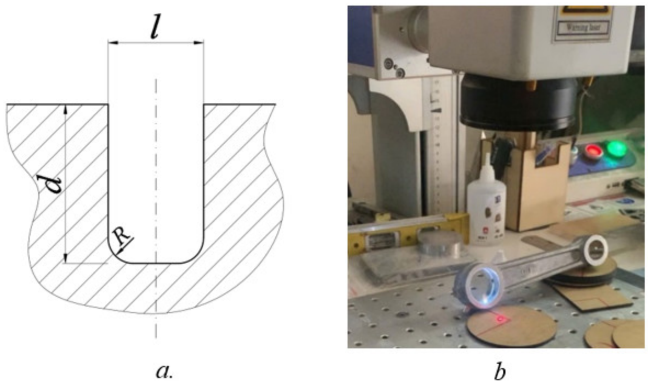

Figure 5. (a) Notch configuration. (b) notches pre-fabricated by laser engraving process

Geometry and geometric dimensions are the main factors that directly affect stress concentration and limit material ductility, directly affecting both directional propagation and surface quality of crack [8, 12, 13]. The parameters chosen in this experiment are the notch depth (d) and the notch width (l), as shown in Figure 5a.

Table 2. Mechanical properties of A356.0 aluminium alloy

Material	Diameter	Ultimate Tensile Strength	Yield Tensile Strength	Shear Modulus	Fatigue Strength	Elastic Modulus	Density
A356.0	$32^{\pm 0,01}$	270 MPa	200 MPa	26 GPa	90 MPa	70 GPa	2.6 g/cm^3

Based on the conducted by L. Zheng et al. [6], the selected range for d and l is d = 0.3 - 0.5mm and l = 0.1 - 0.3mm. The laser machining process setup and operation are illustrated in Figure 5b.

The geometric parameters of the groove were experimentally determined as shown in Table 3.

Table 3. Geometric parameters

Sample	Width (mm)	Depth (mm)	Curvature radius (mm)	Scanning speed (mm/s)	Frequency (Hz)
No1	0.1	0.3	0.08	15	45
No2	0.3	0.3	0.08	15	45
No3	0.1	0.5	0.08	15	45
No4	0.3	0.5	0.08	15	45
No5	0.1	0.4	0.08	15	45
No6	0.3	0.4	0.08	15	45
No7	0.2	0.3	0.08	15	45
No8	0.2	0.4	0.08	15	45
No9	0.2	0.5	0.08	15	45

2.2.2. Design of fracture splitting jig and splitting operation

A hydraulic press YH32-100 was employed for the experiment. Its key specifications are tabulated in Table 4. The fracture splitting parameters mainly include fracture press speed, pressure, backpressure, etc. The research [4] indicates that the width of ductile fracture area becomes narrow and almost constant when the press speed reaches more than 80 - 100mm/s. It seems that it is not necessary to increase press speed any further once it reaches 80 - 100mm/s.

In this experiment, with the YH32-100 hydraulic press, the press speed was 48mm/s with medium force.

Table 4. Specifications of the YH32 - 100 hydraulic press

Specifications	Unit	YH32 - 100
Norminal force	kN	1000
Knock-out pressure	kN	250
Slider stroke	mm	500
Daylight (max height)	mm	800
Descent speed	mm/s	48
Return speed	mm/s	55
Table size	mm	630x630

To transmit and redirect the motion of the slider into a lateral force to split the big end of the connecting rod, a custom-made wedge cone tool was designed and manufactured as shown in Figure 6, with a cone angle of 6°, following the research of Koubota et al. [14].

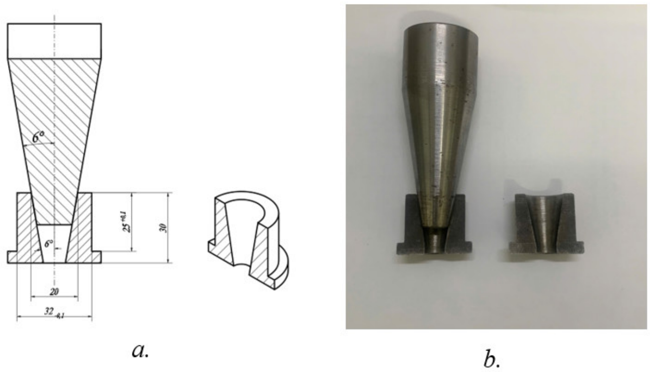

Figure 6. (a) Wedge-cone set blueprint. (b) Real custom-made wedge-cone set

3. RESULTS AND DISCUSSION

3.1. Evaluation on directional propagation of crack

The convex-concave surface after machining ensures the positioning properties of the two halves of the connecting rod's big end, meeting the requirements of the fracture splitting method, as depicted in Figure 7 and Figure 8. Under favorable process parameters, plastic deformation defects that alter the inner diameter of the connecting rod's big-end are limited, which potentially prevents the need for subsequent precision turning operations.

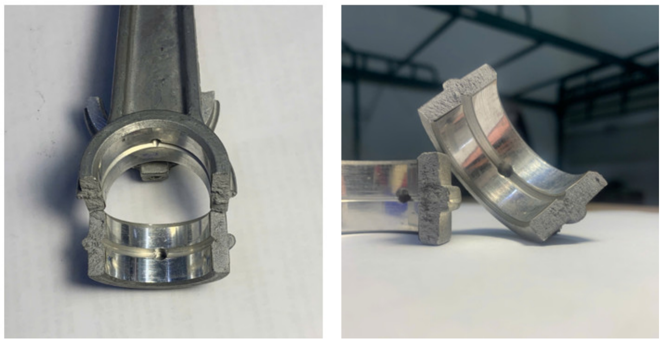

Figure 7. 3D surface after splitting

Figure 8. Assembly profile after splitting

Cracks were initiated at the location of the pre-fabricated kerf and propagated rapidly in metal structure under load within 3 seconds. Overall, the crack propagation is uniform on both halves of the components. However, at the position of the protrusion rib, the stress distribution is not uniform, leading to a continuous change in the crack propagation direction.

3.2. Evaluation on surface quality of crack

The width (l) of the pre-fabricated notch affects the quality surface after machining. At the lower limit of width range (i.e, l = 0.1mm), the cutting process becomes significantly more difficult, resulting in the occurrence of many defects such as metal deficiency and plastic deformation, which cause not only increase in internal diameter size but also thermal damage from laser processing. At the minimum parameters (l = 0.1mm, d = 0.3mm), crack propagation becomes erratic. Gradually increasing the notch depth promotes crack initiation and propagation, while reducing the occurrence of surface defects. In contrast, excessive notch depth in combination with a narrow width can lead to thermal damage from the laser process, resulting in localized material burning. The defects in the minimum parameters are pictured in Figure 9.

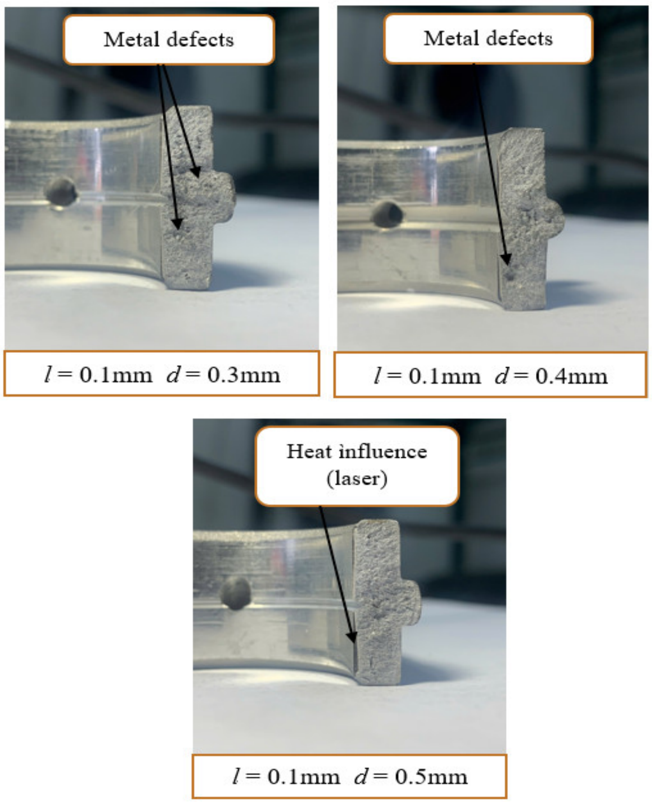

Figure 9. The surface after splitting with a notch width of l = 0.1mm

As the width and depth of the pre-fabricated notch increase, the machining process exhibits greater stability, and the phenomenon of surface metal defects on the machined surface diminishes at a groove width parameter of l = 0.2mm, as illustrated and compared in Figure 10.

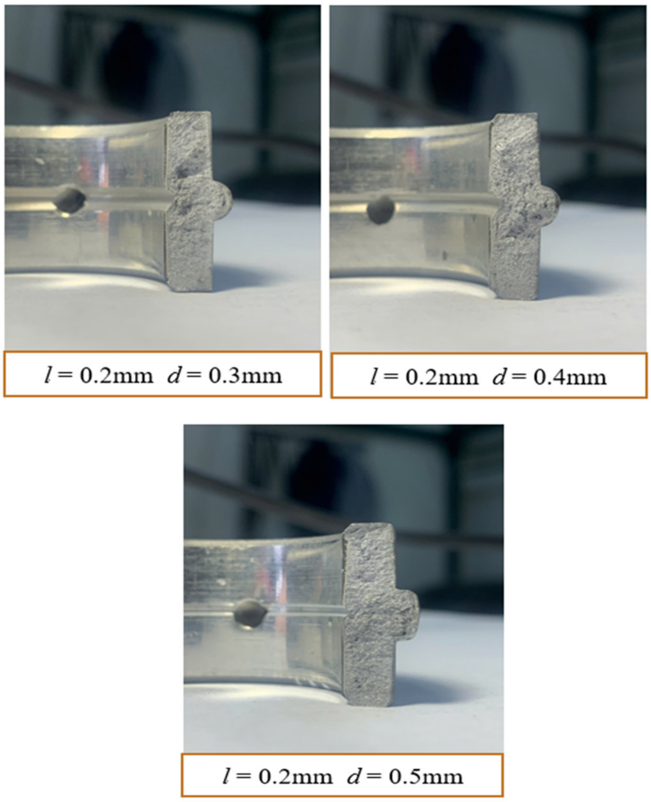

Figure 10. The surface after splitting with a notch width of l = 0.2mm

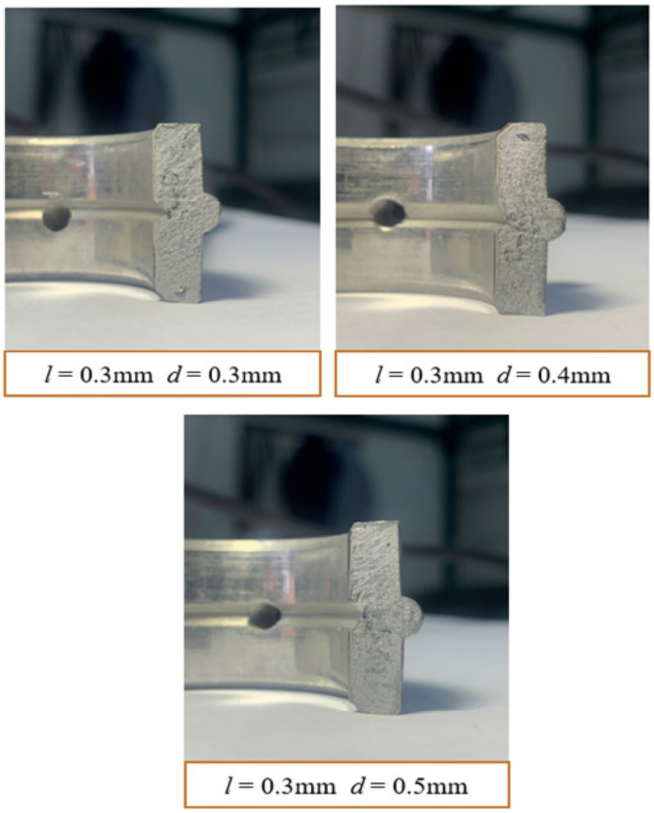

Figure 11. The surface after splitting with a notch width of l = 0.3mm

Moreover, when the groove width parameter reaches l = 0.3mm, as depicted in Figure 11, such defects are virtually eliminated. Additionally, the impact of the laser machining process on the surface metal and the region surrounding the notch is also significantly mitigated. When fixing the notch width l = 0.3mm and gradually increasing the notch depth, the fracture splitting and surface quality improved. However, these improvements were marginal and consistent, showing little variation across different notch depths. Based on this experiment, it is concluded that the optimal dimensions of the pre-machined notch are a width of l = 0.3mm and a depth of d = 0.5mm.

4. CONCLUSION

This paper focuses on the operation of prefabricating kerf by using laser and the directional fracture splitting process of connecting rods, with a deep research on the influence of the geometric dimensions of the pre-fabricated kerf on 3D-fractured surface quality. The conclusions of this research can be listed as follows:

1. A laser-based method was employed to pre-machine notches for the fracture splitting operation of the big-end of the connecting rod. This laser method offers significant advantages over traditional machining techniques, producing notches that meet dimensional and surface quality requirements for the subsequent fracture splitting process.

2. A fracture splitting jig with cone angle of 6° was manufactured and applied to support the fracture splitting process of the big-end connecting rod.

3. For optimal splitting of the medium-sized connecting rod's big-end derived from A356.0 cast aluminum alloy, the proposed pre-machined notch dimensions are width l = 0.3mm and depth d = 0.5mm.

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