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A new conceptual design of compact fatigue crack arresting device

Rizwanulhaque Syed*, JIANG Wei, PEI Fei, ZENG Qing-tuan, YU Zi-chun, GAO Yuan-chang

(School of Mechanical Engineering, Dalian University of Technology, Dalian 116024, China)

Abstract: Fatigue is the major cause of component or structure failure. A novel crack arresting gun providing free operating flexibility to repair/arrest the fatigue crack is designed. It can be automatically operated by PLC control with a robot arm. The nano-material is applied at a certain temperature lower than melting point on local areas of structure or component to repair the crack. The crack arresting gun includes body, handle, camera, nozzle and piston assembly. In this device, the laser is used as heating medium and a temperature sensor enables the material flow after achieving the required temperature. Laser light from a remote source flows through the nozzle central aperture to treat a workpiece. The nozzle central aperture may be surrounded by powder channel outlets aligned upon a working focal point incident after the laser beam. The workpiece is sprayed with powder after heated by laser beam. The shocking pressure may follow the material deposition process. A distance sensor may enable the process of repairing operation according to the presence and detection of a flaw. The crack arresting could be done simply by its compactness and simple mechanism. Conceptual design of the compact crack arresting device gives a high degree of freedom for operating to repair.

Key words: laser (Nd:YAG); crack; crack arresting; nano-material

0 Introduction

Fatigue is the major cause of the engineering failure. In order to arrest the fatigue cracks, various studies have been reported up to now. Numerous methods and devices are used to enhance the fatigue life of engineering components. The welding is the oldest and widely-used methodology to repair the cracks[1]. Recently laser welding is in its infancy and used primarily for exotic applications where no other welding process would be suitable[2].

Applying thermal energy to small areas, there are no other methods as efficient as laser. This ability offers some distinctive metallurgical advantages in some welding/heating treatment applications. Since the surface heating generated by the laser light relies upon the material's heat conductivity to produce the weld, penetration is usually limited to less than 2 millimeters[3]. However, higher power laser ($>$106 W/cm^2) could achieve a deeper penetrations[4].

There are several devices used to repair and

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Corresponding author: Rizwanulhaque Syed* (1983-), Male, Doc., E-mail: syedrizwanulhaq@hotmail.com.

weld the cracks. But in some situations crack arresting could not be done by a conventional process because of some application limitations, such as a specimen size, arrangement of instruments and residual stress after treatment like welding, etc. Worn metal components and assemblies may be repaired through laser processing with a laser source of sufficient intensity to soften the metal surface while a metallic filler in the form of powder is introduced into the softening area. In situations where the work surface is not accessible by conventional methods and workstation-type equipment, a compact crack arresting laser gun is preferred. Other cases may involve the repair of components having irregular and random cracks not otherwise repairable. In order to perform repairs of the cracks, a portable and flexible delivery system is required for laser, filler as well as compressive stress. This design provides for these needs through the combination of laser beam, nano particles or metal powder delivery and piston components into a compact unit. The laser source is a continuous wave of Nd: YAG laser.

1 Working principle of the fatigue crack arresting gun

In general, the surface of a metallic material may be welded and/or alloyed by the simultaneous and cooperative operation of a laser beam and an alloy powder flow stream. To accomplish this purpose, systems exist that have a laser source and focusing apparatus, with a powder delivery apparatus provided as part of an integral package. The laser beam heats a relatively small area at the surface of the article, and controlled volumes of alloying particles are delivered into the melt pool via the powder flow stream[5].

In conventional devices the crack is repaired through welding, it leaves the residual stress. A new conceptual device, compact crack arresting laser gun is designed. The crack arresting laser gun treats metallic materials by the cooperative operation of a laser beam, nano-material stream and pressure shock as per the condition. To accomplish this aim, system having a laser source, focusing apparatus is invented with nano-material delivery tank as part of an integral package. The laser beam softens (less than the melting point of metallic material) the crack tip on the surface of the article; a controlled volume of nano particles is delivered into the softening pool via powder flow stream at a certain velocity. Later, the pressure may exert if needed. This laser gun gives the free ability for the user to manipulate it in a conventional manner during the repairing process.

2 Methodology

The design methodology consists of the details of the designing. Fig. 1 is the practical presentation of the steps of the methodology. This paper surveys the crack arresting techniques and methodology, furthermore, covers the device and mechanism being used. The aspects are reviewed critically and the limitations of the existing device and methodology would be overcome. According to the application environment, the laser power, beam size, filler and sensor can be changed.

In the laser energy calculation, as in this technique, the operating temperature is lower than the melting point of the substrate.

Knowing the size of the focused spot is helpful in calculating energy density on the work surface.

For a fundamental mode (transverse electromagnetic mode, TEM) beam:

$$S = \frac{4\lambda}{\pi} \times \frac{F}{D} \tag{1}$$

Where S is the focused spot diameter; λ is laser wavelength; F is focal length of objective lens; D is diameter of laser beam.

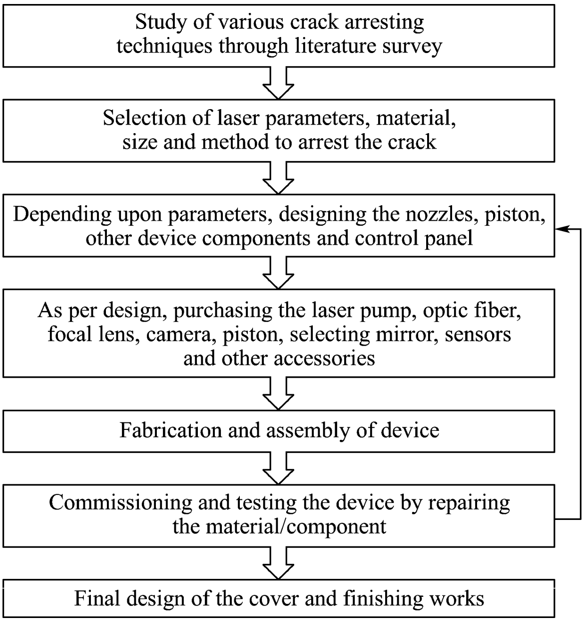


Fig. 1　Design methodology

In performing a laser treatment, optic lens to focus the laser beam to the desired size are necessary. For a multimode beam:

$$S = F\Phi \tag{2}$$

Where Φ is the laser beam divergence.

If one assumes the part to be repaired as a semi-infinite solid, with a constant incident heat flux, the temperature distribution as a function of depth into the material is given by[6]:

$$T(x,t) = \frac{2E}{K} \times \left[\left(\left(\frac{kt}{\pi} \right)^{1/2} \times \exp\left(-\frac{x^2}{4kt} \right) - \frac{x}{2} \right) \times \mathrm{erf}\left(\frac{x}{2}(kt)^{1/2} \right) \right] \tag{3}$$

Where $T(x,t)$ is temperature at a distance x below the work surface, at a time t after start of constant heat input; E is constant heat flux input; K is thermal conductivity; k is thermal diffusivity; erf(·) is complimentary error function.

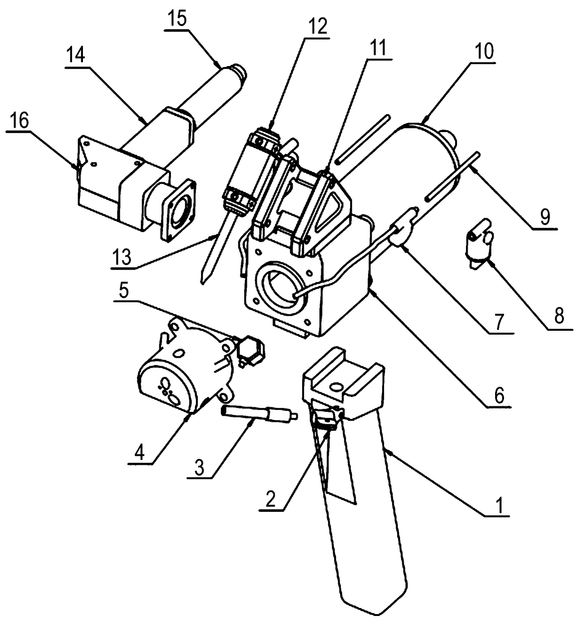
And on the surface ($x = 0$), the temperature rise will be:

$$T(x,t)\big|_{x=0} = \frac{2E}{K} \times \left(\frac{kt}{\pi} \right)^{1/2}$$

After that, the components (camera, temperature sensor, crack flaw sensor) are designed and purchased as per design. Fabricating and assembling the device, and testing it practically, and if it's necessary to adjust the component's accessories and their parameters. Process is finished for a better look, safety and easy to operate.

3　Device model

The CAD exploded model of the crack arresting device is shown in Fig. 2. It demonstrates the main parts of the device.



1 handle; 2 handle pin; 3 distance sensor; 4 nozzle cover protecting the micron nozzle; 5 temperature sensor; 6 main body; 7 material flow sensor; 8 nano powders tank; 9 flexible pipe for air/gas supply; 10 optic fiber connector; 11 piston support; 12 cylinder; 13 piston; 14 camera; 15 mirror assembly; 16 camera connector

Fig. 2　CAD exploded model of the crack arresting device

Cross sectional view of the device is shown in Fig. 3, which defines the arrangement of the parts and gives a glimpse of assembly. The parts and materials are listed in Tab. 1.

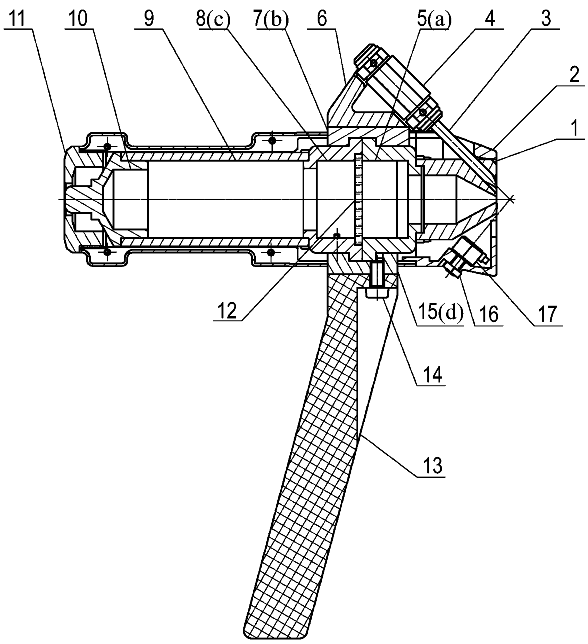


Fig. 3 Cross sectional view of crack arresting device

Tab. 1 Crack arresting device parts and materials

No.	Parts	Materials
1	a nozzle	silicon nitride
2	front cover	aluminum-6061
3	mandrel	carbon steel
4	cylinder	stainless steel
5	connector(a)	stainless steel
6	cylinder bracket	aluminum-6061
7	connector(b)	stainless steel
8	connector(c)	stainless steel
9	laser focus module	stainless steel
10	optic fiber connector	
11	optic fiber holder	aluminum-6061
12	dichroic mirror	glass
13	handle	ABS plastic
14	screw (GB/T 2171.1) M5×10 14	low carbon steel
15	connector(d)	stainless steel
16	nuts (GB/T 6174) M4 16	low carbon steel
17	distance sensor	

4 Discussion

The present invention provides a hand-held crack arresting laser gun. It allows customized fatigue crack arresting by delivery of laser light, nano-particles and compressive stress. The laser heats the articles to soften the small area. The nano-particles follow the laser with certain velocity in the softening pool. The ability to provide such a compact crack arresting system increases convenience, facilitates the user to repair objects with higher skill, flexibility and efficiency.

In one embodiment, the laser gun includes a body, a nozzle assembly mounted on the body and a piston assembled on the nozzle. The nozzle assembly defines a nozzle central aperture, through which gas and light, including laser light, may pass. The nozzle defines the first and the second powder flow channels aligned with a working focal point adjacent to the nozzle central aperture. The nano-material powder may be transmitted through the first and the second powder flow channels for repairing after a laser light transmits through the nozzle central aperture.

In another embodiment, a method is provided to manually arrest a crack on a workpiece in order to repair. The nano-particles-fed laser gun is provided which can be manually operated. In such manual operation, the gun generally enjoys significant degrees of spatial freedom so that the operator may dispose the gun in a variety and number of easily-achieved positions. In this way, the operator may conform his activities to the needs at hand and is preferably not limited by physical constraints of the laser gun.

Other features and advantages of the present invention will become apparent from the following description of the preferred embodiment, taken in conjunction with the accompanying drawings, which illustrate, by way of example, the principles of the invention.

5 Conclusion

A novel conceptual design of compact fatigue crack arresting device is studied. It consists of a body, handle, camera, nozzle and piston assembly (optional). Construction of compact fatigue crack arresting device (manually operated) is given. It is achieved by its compactness and simple mechanism. It can be automatically operated by PLC control with a robot arm. The crack arresting could simply be done. It retards the fatigue crack growth in the local area by impacting coherent beam of light on a crack flaw. The crack tip is heated below the melting point of substrate and nano-filler is added. Then, an optional process applies the residual compressive stress with aid of piston and the crack propagation is retarted.

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一种新型简捷式疲劳裂纹修复仪概念设计

Rizwanulhaque Syed*，蒋　玮，裴　斐，曾庆团，于子淳，高远长

(大连理工大学 机械工程学院，辽宁 大连　116024)

摘要：疲劳是零件或结构失效的主要原因.为此设计了一种操作灵活的新型疲劳裂纹修复仪，其可通过可编程控制器和机械臂实现自动工作.纳米材料在低于零件或结构熔点的温度下被用以修复裂纹.裂纹修复仪主要由机身、手柄、相机、喷嘴和活塞组成.其利用激光作为热源，温度传感器对温度进行检测并对纳米材料流通道进行控制.来自外部光源的激光通过喷嘴中心孔照射到工件裂纹处，喷嘴中心孔被粉末通道的出口环绕，粉末出口的方向和激光的焦点重合，在激光加热工件之后喷上粉末，并在材料沉积工序之后进行压力冲击.距离传感器能够使修复过程随着裂纹的发现和探测来进行.本设计结构紧凑，原理简单，可以高效完成裂纹修复.

关键词：激光(Nd:YAG)；裂纹；裂纹修复；纳米材料

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作者简介：Rizwanulhaque Syed* (1983-)，男，博士生，E-mail：syedrizwanulhaq@hotmail.com.