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Investigation of delamination mechanisms during a laser drilling on a cobalt-base superalloy☆

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ABSTRACT

Temperatures in the high pressure chamber of aircraft engines are continuously increasing to improve the engine efficiency. As a result, constitutive materials such as cobalt and nickel-base superalloys need to be thermally protected. The first protection is a ceramic thermal barrier coating (TBC) cast on all the hot gas-exposed structure. The second protection is provided by a cool air layer realized by the use of a thousand of drills on the parts where a cool air is flowing through. The laser drilling process is used to realize these holes at acute angles. It has been shown on coated single crystal nickel-base superalloy that the laser drilling process causes an interfacial cracking (also called delamination), detected by a cross section observation. The present work aims at characterizing interfacial cracking induced by laser drilling on coated cobalt-base super alloy. On the one hand, this work attempted to quantify the crack by several microscopic observations with regards to the most significant process parameters related as the angle beam. On the other hand, we studied the difference of the laser/ceramic and the laser/substrate interaction with real time observation by using a fast movie camera.

1. Introduction

In order to reduce gases emission and improve engine efficiency, temperatures in the high pressure chamber of aircraft engines are continuously increasing (currently up to 2300 K). As a result, constitutive materials such as cobalt and nickel-base superalloys need to be thermally protected. The first protection consists in covering the hot gas-exposed structure with a ceramic thermal barrier coating (TBC) and a bond coating (BC) (Fig. 1). The second protection is provided by a cool air layer produced by the use of thousands of drills made on the components through which a cool air is flowing. This protection method is illustrated in Fig. 2 where the typical geometry of a turbine blade in an aircraft high pressure chamber is shown.

Laser drilling is a non-contact machining process which is very useful to make acute angled holes. Two different drilling modes, labeled as percussion drilling and trepan drilling are typically used in the industry. The percussion mode is a fixed beam drilling whereas the trepan mode involves cutting with a circular trajectory centered with the hole. The range of power density generally used for both trajectories is about 1–50 MW/cm^2 during a pulse of about 1 ms. In percussion drilling mode, multiples pulses are produced until the breakthrough of the sheet. The advantage of this last method with regard to the trepan mode is a reduction in processing time by a factor of four (Sezer et al., 2006). In this range of power density, the physics process consists in heating the surface by focusing the laser beam with temperatures up to the vapor point. The melt part is then ejected by the vapor pressure and the hole is created (Semak, 1997). In this study, only the percussion mode was used to drill.

Laser drilling induces different types of defects such as a recast layer and spatters on the surface (Sezer et al., 2006) which are already observed in literature by means of cross section observation. Especially, the effect of the process parameters on the different heat affected layer across the hole was studied. Voisey et al. (2004) studied the effect of assist gas pressure on the geometry and the residual metallurgical state after a percussion laser drilling. It has been reported that the pressure and the nature of the gas have no mechanical or chemical effect on the component. On the contrary, the angle beam, its power density and the repetition rate are three parameters which modify the geometry of the hole and the size of the recast layer.

But as report in Sezer et al. (2006) and Sezer and Li (2009), the major default is the delamination of TBC. Delamination is cracking which leads to failure of the coating, damaging the turbine engine.

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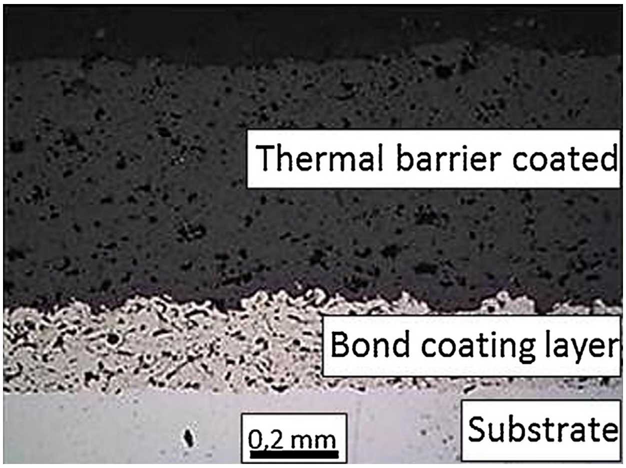

Fig. 1. Micrography of the multilayer material used in critical aircraft parts.

The frequency of multipulses is the major factor for the localization of the delamination (Sezer and Li, 2009). At low frequency (around 1 Hz), the crack initiates at the BC/substrate interface due to several thermal shock cycling and the associated thermally grown oxide. At high frequency (around 10 Hz), it is located at the BC/TBC interface which is a major threat to the integrity of the engine. The integrity of the component is assessed by the delamination length: the larger, the more harmful. The delamination length increases with the angle beam and is commonly measured in the cross section of the hole (Sezer et al., 2006; Voisey et al., 2001; Kamalu et al., 2002) using optical micrographs.

Results in literature refer to a nickel-base superalloy substrate. The material drilled in this study is the cobalt-base superalloy (Haynes 188 (HS188 or ams5608)) which offers high strength and oxidation resistance to 1100 °C (Van Deventer, 1977) and is used in turbine engine typically working at 2000 °C. The substrate is covered with a ceramic coating. The present work aims at describing and quantifying delamination induced by percussion laser drilling at various angles on this multilayer material. Laser repetition rate is 10 Hz. Thus, the observed crack is expected to be located at the BC/TBC interface. The first section goes over longitudinal section observations of the holes pulse after pulse with a new approach to observe the evolution of the crack. The second section shows a new investigation to observe the morphology of the crack surface always with a micrography observation. Furthermore, visualization in real time of the laser drilling with a fast camera allowed us to discuss phenomena in relation with material observations.

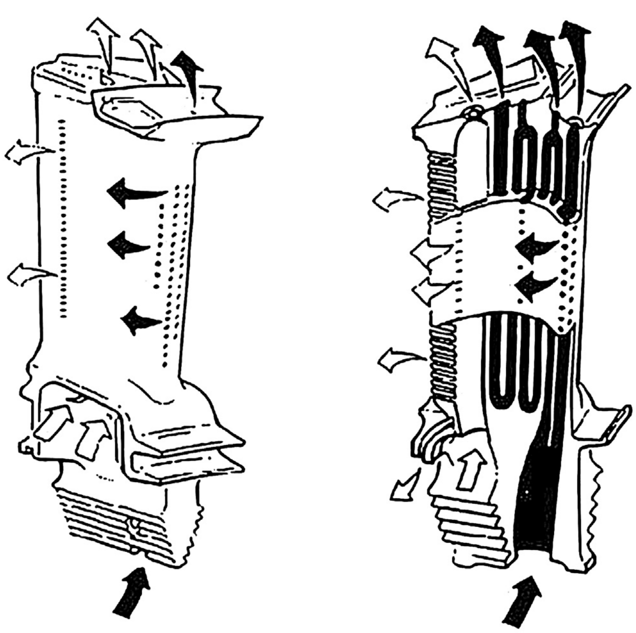

Fig. 2. Representation of the cooling method of turbine blade using thousands of holes in which a cool air is flowing in a turbine blade.

Table 1
Plasma spraying parameters.

Ceramic layer powder	YSZ
Binding layer powder	NiCrAlY
Ceramic layer plasma gas flow	30 l/min (Ar)
Binding layer plasma gas flow	4 l/min (H_2)
Spray distance	80 mm
Number of passes	from 5 to 10

2. Experimental set up

2.1. Materials

The laser-drilled material was a multilayer material. The metal substrate was a cobalt-base superalloy used in the manufacture of aircraft components. Its denomination is "Haynes 188" or "HS188" or "ams5608". A nickel/chromium (NiCrAlY) bond coating was first sprayed on the workpiece surface to enhance the adhesion of the thermal barrier coating. The thickness of the BC is around 0.2 mm. The TBC consisted of a Zirconium–Yttrium oxide ceramic and is 0.5 mm thick. The manufacturing process is the conventional plasma spraying (Fauchais, 2004) and parameters are listed in Table 1. Laser drilling was carried out on sheets of 2 mm.

2.2. Process and fast camera parameters

The laser source is a TRUMPF HL201p (Nd:YAG) operating at 1.064 μm. It delivers a reliable circular and uniform spatial intensity distribution of light. The beam spot diameter can be fixed whatever the peak power of the laser source. It was here equal to 300 μm. The absorbed intensity which is the effective energy can be deduced from the peak power measurement (Schneider et al., 2007a, 2008). In this study, the incident intensity, so called I_{inc}, was held constant and equal to 18.4 MW/cm^2 which coresponds to a peak power of 13 kW. The focal distance was held constant for all the drillings. The work piece was drilled from TBC side. One to eight pulses with a frequency of 10 Hz were delivered. The pulse duration is 1 ms. The shot angles, so called β, were selected equal to 20°, 30° and 40° because they induced delamination on nickel-base superalloy AM1 with coating (Kamalu et al., 2002). Shots at 90° were also performed as shot references. Oxygen assist gas was used coaxially with the laser beam via a 1.5 mm exit diameter converging nozzle. The gas pressure was held constant at 6 bar.

The laser process parameters are listed in Table 2:

A Photron RS 250k camera with a band pass filter was used to investigate the fluid ejection dynamics following the work of Schneider et al. (2007a). The experimental set up is described in

Table 2
Laser process parameters.

Laser source	TRUMPF HL201p (Nd:YAG)
Laser incident intensity	I_{inc} = 18.4 MW/cm^2
Beam diameter	300 μm
Pulse duration	1 ms
Assist gas	O_2
Shot angle	β = 40°, 30° and 20°
Number of pulse	from 1 to 8 pulses
Repetition rate	10 Hz