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Optimising laser cut-edge durability for steel structures in high stress applications

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ABSTRACT

The integrity of steel beam components in high intense stress applications have been observed to be influenced by the condition of the cut edge properties. The cut-edge characteristic properties formed during laser-cutting processing have been over prolonged periods determined to have beneficial effects on fatigue life. During this study two high strength steel grades S355MC and DP600 have been examined. This is important in the case of high strength steels, these were shown to display an increased sensitivity to fatigue cracks initiating from cut-edge regions. It was determined that by controlling the interrelationship between power and traverse cutting speed during the laser cutting process can result in optimised fatigue lives being achieved. Optimal fatigue lives were attained by minimising the laser cut-edge surface damage, maintaining the formation of shallow striations and by controlling the near edge microstructural deformations during each cutting process. This was validated using a bespoke automotive component in which was tested under four-point loading.

1. Introduction

Laser cutting of advanced high strength steel grades has numerous advantages over conventional mechanical blanking in terms of minimising the cut-edge surface damage [1–5]. The advantage of laser processing is with the high flexibility and its ability to cut sheet components with intricate geometries at high precision, while producing a high cut-edge quality. Maintaining the correct control of laser cutting parameters can result in high quality cut-edges produced even at high cutting speeds. When using optimum process parameters the advantages gained by using the laser, are a small kerf width combined with the generation of only a narrow heat-affected zone (HAZ). Laser radiation heats the steel and an assist gas jet exerts momentum onto the molten material, leading to the ejection of the melted mass through the bottom of the cut-edge [6]. At low cutting speeds the conductive heat-flows into the material and dominates the convective component, resulting in a supplementary heat discharge. Conversely, at high cutting speeds the heat released at the surface of the cut-edge can reach the cutting front through a mechanism of heat conduction. It is impractical to investigate each of the laser cutting parameters at one time [7]. Therefore, it is paramount to identify the dominant factors for which variation could lead to large effects on cut-edge quality. The most critical laser cutting process parameters in order of importance are; laser power, traverse cutting speed, assist gas pressure and the assist gas type. It is these parameters that significantly influence cut-edge quality during the laser cutting process [8].

Optimum laser cutting process parameters can produce a 0.1 mm accuracy tolerance [9]. When using optimised laser process settings the cutting speed can be increased up to 5000 mm/min [10]. However, high-quality cut edges can only be obtained up to a cutting speed of 3000 mm/min using oxygen assist gas at a pressure of 200 kPa for a steel work piece [11]. As the cutting speed is increased the kerf width decreases, this can occur even at a high laser power of 1500 W. The increase in the kerf width and surface distortion is more prominent as the cutting speed is decreased which causes an increase in the energy-coupling factor [12]. However, the sharp focusing of laser radiation is necessary for high-speed cutting of thin sheet steels [13]. The dominant process for different laser material processing techniques is as a function of laser energy and matter interaction. The processes are divided into three major classes, namely involving heating, melting or vaporising the workpiece [14]. A significant proportion of heat is concentrated in the melted material and removed from the kerf via the pressurised assist gas [13]. The temperature distribution is localised in the thin cut-edge surface layer and the energy coupling at the workpiece surface is important in terms of determining the cut-edge microstructural properties.

Using high power intensity can therefore result in the beam being absorbed by the workpiece material, which can cause undesirable solid-state heating, melting and vaporisation of the workpiece material, as well as further problems such as workpiece distortion. The assist gas parameter interacts as a hydrodynamic process that melts the workpiece material and removes it instantly through the bottom of the cut-edge. There are two types of assist gas used in laser cutting, reactive and non-reactive [15]. Reactive gases are used to cut low alloy steels, in which the oxygen reacts with the iron to create heat, leading to

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Nomenclature

A	Elongation to Failure
AHSS	Advanced High Strength Steel
HAZ	Heat-affected zone
HCF	High Cycle Fatigue
HSLA	High Strength Low Alloy
H_V	Vickers Hardness
kPa	Kilopascal
R_a	Arithmetic mean of departures from the mean line
R_p	Maximum height of profile above the mean line
R_v	Maximum depth of profile below the mean line
S-N	Stress Life
Wt	Weight

increases in either the thickness that can be cut or the cutting speed at low pressure. Non-reactive gases are delivered at higher pressures in order to exert the necessary momentum on the liquefied material.

The assist gas in the cut kerf causes a shear stress on the molten material, resulting in a laminar flow of this molten layer [16]. Numerous research studies have been conducted to examine the effect of assist gas during the laser cutting process. Experimental results showed that the use of oxygen as an assist gas resulted in better quality cut-edges than when nitrogen and argon are used to cut stainless steel [17]. When cutting mild steel then oxygen assist gas cutting produces the best cut-edge quality [18]. The use of oxygen as an assist gas at low traverse cutting speeds results in the formation of a wavy cut-edge. The size and properties of the HAZ are also of importance due to the high potential for local degradation leading to embrittlement of the cut-edge. The increase of the kerf width further increases the size of striations formed on the cut-edge surface. Surface striations are primarily the cause for laser cut-edge roughness and are the paramount quality characteristic in laser cutting, and the formation of these features relates to both the cutting process and workpiece properties [19–22]. Surface striations increase in size as the laser power output is increased and the effect is amplified as the cutting speed decreases because of an increase in the energy-coupling factor.

2. Experimental methods

2.1. Material properties

The two high strength steels used in this study were selected; S355MC is a high strength low alloy (HSLA) steel grade and DP600 which is a dual phase, ferrite and martensite. The microstructures of these steels are shown in Fig.. 1 and Table 1 presents the steel chemistry and mechanical properties.

2.2. Laser processing

Laser cut-edges were generated using a Prima Industria Platino 1325 CO_2 laser as shown in Fig. 2. The cutting parameters used for generating laser cut-edges are shown in Table. 2. For comparison milled edges, denoted as ‘smooth’ during this study were generated using a Hardinge VMC600II CNC milling machine.

2.3. Characterisation

Surface micrographs of laser cut-edges were captured using a Leica optical light microscope. Microstructural characterisation and HAZ size measurements were analysed through observing the specimens traverse to the cut-edge. Metallographic analysis of the near edge region microstructure was carried out by etching specimens using a 2% Nital reagent for 10 s. The microstructures were observed using a Reichert Polyvar optical microscope. In order to record and quantify cut-edge surface properties, a Taylor-Hobson form 2 Talysurf was employed with scans being carried out across a two-dimensional surface area, providing an accurate representation of the cut-edge roughness and waviness data parameters together with the generation of axonometric profiles. The degree to which the cut-edge surfaces had hardened was measured as Hardness Vickers (H_v) microhardness, and measurements were taken using a Leco M-400-G2 hardness tester with a 100 g load.

2.4. Fatigue life testing

Stress life (S-N) fatigue testing was conducted using a Dartec 50 kN servo-hydraulic testing machine with a K7500 controller and the stress

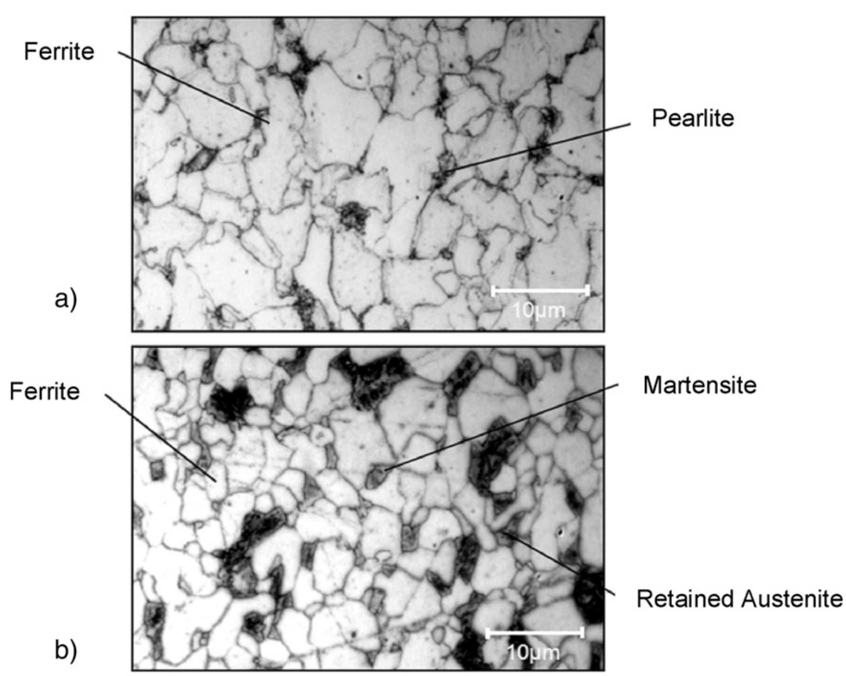

Fig. 1. Microstructure of S355MC and DP600 steels etched with 2% nital.