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Optimization of process parameters for high efficiency laser forming of advanced high strength steels within metallurgical constraints

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Abstract

Laser forming (LF) has been shown to be a viable alternative to form automotive grade advanced high strength steels (AHSS). Due to their high strength, heat sensitivity and low conventional formability show early fractures, larger springback, batch-to-batch inconsistency and high tool wear.
In this paper, optimisation of the LF process parameters has been conducted to further understand the impact of a surface heat treatment on DP1000. A FE numerical simulation has been developed to analyse the dynamic thermo-mechanical effects. This has been verified against empirical data. The goal of the optimisation has been to develop a usable process window for the LF of AHSS within strict metallurgical constraints. Results indicate it is possible to LF this material, however a complex relationship has been found between the generation and maintenance of hardness values in the heated zone. A laser surface hardening effect has been observed that could be beneficial to the efficiency of the process.

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Keywords: Laser forming; laser; optimization; AHSS; micro hardness

1. Introduction

Advanced high strength steels (AHSS) are an automotive grade of steel which are of a significant interest to manufacturing industries due to their high strength when compared to conventional steels, which leads to a

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reduction in weight and crash risk. This paper is concerned with Dual Phase Steel (DP1000), which is one of the most widely used types of AHSS by car manufacturers (*Kuziak, A. Camoletto*).

Dual phase steel (DP) has a microstructure composed of soft ferrite and 10-40% of hard martensite or martensite-austenite islands (*J .R. Bradley*). The strength of the DP steel microstructure is determined by the amount of martensite which is developed by the transformation of austenite during quenching after hot rolling or annealing (*Kuziak*).

A major disadvantage of dual phase steels is their resistance to deformation and spring back effects in comparison with conventional steels. According to *Neugebauer*, heat treatment of the DP steel leads to an increased formability comparable to conventional mild steels, without spring back. *Neugebauer* recommended a laser heat treatment to improve the formability locally without compromising the whole bulk strength.

Laser forming (LF) is a non-contact process of shaping metallic and non-metallic sheets by inducing thermal stress using a de-focused laser beam without any melting. Laser forming has a potential of the industrial promise of controlled shaping of metallic and non-metallic components for prototyping, correction of design shape or distortion and precision adjustment applications.

The thermal stress can induce permanent plastic strains bending, shortening or buckling the work-piece depending on the geometry, process parameters and the mechanism active.

This work is concerned with the shortening mechanism (Edwardson et al) where a large beam diameter compare with the thickness and slow process speed induces in-plane shrinkage. This is particularly useful for the forming of tubular and box section geometries used in structural component in the automotive industries. Recent work has shown the process can be used to form square section tubes (Sheikholeslami et al).

Laser forming has been shown to be a viable alternative to locally heat and form AHSS despite the sensitivity of material to heat. Griffiths et al. investigated the potential to form heat sensitive dual phase steel by the laser bending process within metallurgical constraints by optimisation of process parameters. Griffiths classified two temperature regimes where the DP 1000 experienced a reduction in hardness. Within a low temperature heating regime a loss of tetragonality in the martensite region resulted in a slight reduction in hardness. Within a higher temperature regime of greater than the upper critical transformation temperature in mild steel of equivalent carbon content (1000-1140 K) a major loss of hardness was observed due to austinization effects.

Further studies presented in this paper on dual phase steel (DP1000) indicate a more complex relationship between the generation and maintenance of hardness values in the heated zone. A laser surface hardening effect has been observed that could be beneficial to the efficiency of the forming process.

Laser surface hardening depends on laser processing variables as well as interaction time to produce a martensitic structure in steel (J.Senthil Selvana et al).They characterised the laser transformation hardening process into three basic steps; An increase in temperature above a critical point of the steel (Ac1) followed by rapid self-quenching into the bulk material. Typically in low carbon steels as the surface temperature is brought to 980–1773K within a short interaction time the original pearlite morphology transforms into a metastable martensite which increases the hardness not only on the surface of the steel but to a depth of 0.2-1 mm. DP1000 is also considered a low carbon steel and so should behave in a similar way.

In this paper, optimisation of the laser forming process parameters has been conducted to further understand the impact of a surface heat treatment on 1.2mm thick DP1000. A FE numerical simulation has been developed to analyse the dynamic thermo-mechanical effects. The goal of the optimisation has been to develop a usable process window for the laser forming of AHSS materials within strict metallurgical constraints.

2. Experimental

An initial empirical study was conducted on graphite coated DP 1000 steel sheet with the thickness of 1.2 mm using a 1.5kW CO_2 TEM_{00} laser (operating at a wavelength of 10.6 µm and in continuous wave mode) and an industrial 5 axis gantry. The speed range was from 15 mm/s to 45 mm/s with the beam spot size of 8 mm and laser power of 600 W and 1000 W. The pass numbers were from single to five passes.

To study the effect of the process on the metallurgical properties of the material, a Vickers micro hardness test with the specification HV 0.1/10 with 1 kg load was used to measure the hardness of the samples; the specific sample preparation is described in Sheikholeslami et al.

A FE numerical simulation has been developed in COMSOL Multi-physics vs 4.4 to analyse the dynamic thermo-mechanical effects. The intensity distribution I of the incident laser beam was approximated by a Gaussian