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# Local heat treatment of a laser build-up

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## Abstract

Laser cladding or laser metal deposition involves the deposition of any weldable material onto the surface of a metal substrate by means of a laser beam. Although clad deposits are fully fusion-joined to the substrate material, the very low heat-input associated with laser cladding results in extremely low dilution as well as relatively small heat-affected zones (HAZ). Subsequent to the clad-repair process, heat treatment is normally not necessary, but some critical components may require it due to the high hardness obtained in the HAZ. Conventional heat treatments are most often time-consuming, costly and could cause possible distortion of the component. In this study local laser heat treatment of the HAZ after laser cladding has been investigated on different substrate materials (21CrMoV5-11, X22CrMoV12-1, 34CrNiMo6) as an alternative to full post-weld heat treatment (PWHT). Due to the focused heat of the laser beam, the required time at temperature for heat treatment was only a fraction compared to that of conventional heat treatments. It was observed that the HAZ hardness could indeed be lowered significantly by controlling the temperature and interaction time of the local treatment. For 21CrMoV5-11 the HAZ hardness was decreased to below 400 HV with most treatments at 800 °C, but the 8 s interaction time was found to be optimal. The X22CrMoV12-1 material showed the highest resistance to PWHT and only the longest interaction time at 800 °C resulted in HAZ hardness close to 400 HV. The largest decrease in HAZ hardness was obtained with the 34CrNiMo6 material and the longest interaction time at 700 °C resulted in the lowest hardness.

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*Keywords:* Laser; cladding; heat-affected-zone; local heat treatment; hardness

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## 1. Introduction

During the fabrication process, welding is the most commonly used method of joining parts together. The result of the welding thermal cycle is non-uniform heating and cooling of the material which causes distortion if the welded item is free to move, residual stress if the part is securely held, a heat-affected zone (HAZ) and cold cracking susceptibility in the weld, HAZ, and base metal [1]. The heat-affected zone is the volume of material, at the interface between the weld metal and parent metal, which properties have been altered due to the heat input of the welding process. Welding causes hardening in the HAZ due to martensite formation and this microstructure is responsible for the property deterioration of the weld. Effective post-weld heat treatment is the primary means by which heat-affected zone properties are corrected [2,3].

The advantages of laser cladding, which is a welding overlay process, are that of localized heating combined with accurately controlled weld metal deposition resulting in low distortion and a small HAZ. However, even with these advantages, residual stresses in the weld area are inevitable and in some instances it is required to manage and reduce these stresses to prevent failures [4].

Post-weld heat treatment is the most widely used form of stress relieving on fabrication completion of welded carbon and low-alloy structures. In the context described here, PWHT refers to the process of reheating the weld to below the lower transformation temperature at a controlled rate, holding for a specific time and cooling at a controlled rate [1]. In this process the high hardness of the HAZ and also that of the weld are considerably reduced, ductility and notch toughness are improved and diffusible hydrogen is dissipated [5]. The PWHT process usually involves placing the entire component in a furnace, which can be impractical for large components, ‘difficult to remove’ components and where distortion is a concern. Localized PWHT is then employed to solve these issues, or when a furnace treatment is not cost effective. Local PWHT may be carried out using high velocity gas burners, infrared burners, induction heating or high resistance heating elements [6]. Laser heat treatment is ideally suited to the precise, local heat treatment of metallic materials, enabling the specific modification of properties on specific areas of components [7]. Unlike the conventional furnace treatment which can take at least several hours, this technique invariably also involves heat treatment cycle times in the region of a few seconds and the volume of the treated material acts as quenching agent. The depth of the heat treated zone is dependent on the heat input, but can range between 0.25 and 2.5 mm [1,7]. Heat treatment using laser radiation is normally applied to harden metals, but in principle metal softening through laser radiation should also be possible. Since laser clad repair normally involves a relatively small area of interest, this paper investigated the use of laser as an effective tool for localized heat treatment. Single clad tracks were used in order to isolate the effect of the heat treatment on the HAZ by eliminating the influence of overlapping clad tracks.

Three different substrate materials were used in this investigation. These were 21CrMoV5-11, X22CrMoV12-1 and 34CrNiMo6 (EN4). CrMoV materials are creep resisting alloys for elevated temperature service up to about 580°C, with a reasonable degree of corrosion resistance in superheated steam. Typical applications for the cast material include valve casings and steam turbines, general use for boilers and pressure vessels in the power generation and petrochemical industries. 34CrNiMo6 is a high-strength alloy steel and a popular through-hardening grade. Applications include heavy duty shafts and gears. High-strength steels exhibit a complex microstructure made up of martensite, austenite, pearlite, ferrite and carbides and the softening mechanism is based on the tempering of the martensite or partial austenitization with subsequent ferrite-pearlite transformation upon slow cooling [8].

## 2. Experimental

A fibre coupled Rofin Sinar DY044 Nd:YAG laser was utilised for the deposition of single clad tracks onto the different substrates. The typical chemical composition of the substrates are given in Table 1. The clad metal (consumable) was 1.7339 powder (0.1C-1Mn-0.6Si-1Cr-0.5Mo) of -90 +45 µm particle size. The powder was carried to the workpiece by means of a GTV powder feeder together with an ILT (Fraunhofer Institut für Lasertechnik) three-way cladding nozzle (Fig. 1). A Mergenthaler fibre-coupled, high speed infrared pyrometer with a unique, closed-loop LASCON® measurement and temperature control system was attached to a Precitec YW50 laser head and the pilot light was aligned to coincide with the laser spot on the surface of the substrate (Fig. 1).

Table 1. Typical chemical analysis of the substrate metals used in this study (weight percentage).

| Steel type | C | Cr | Mo | Ni | V | Mn |
|---|---|---|---|---|---|---|
| 21CrMoV5-11 | 0.2 | 1.4 | 1.1 | ≤0.6 | 0.3 | 0.5 |
| X22CrMoV12-1 | 0.2 | 12.0 | 1.0 | 0.6 | 0.3 | 0.7 |
| 34CrNiMo6 | 0.4 | 1.2 | 0.3 | 1.5 | - | 0.6 |

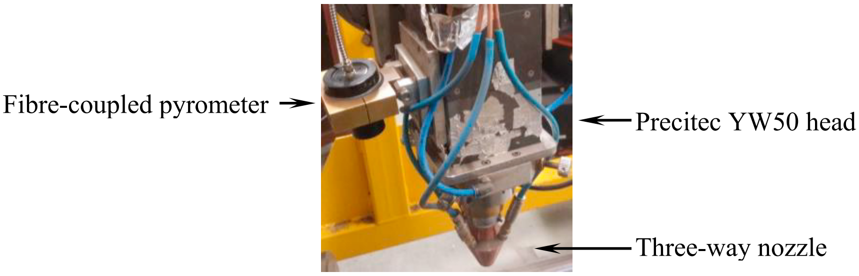

Fig. 1. Set-up for the cladding and local heat treatment process.

By measuring the actual surface temperature the laser power could be controlled in such a way that the temperature and corresponding heat treatment depth were maintained at the required level. LASCON® therefore controlled, optimised and supervised the laser process. The time-temperature-power output graphs were recorded to verify whether the set temperature was reached during the heat treatment run.

The cladding of single tracks was done with the parameters given in Table 2 and the local heat treatment with parameters in Table 3. The output laser power was limited to .7 kW The substrate thickness was 30 mm to ensure a representative heat treatment effect. The selected laser spot sizes for the local heat treatment were 8 mm and 12 mm, which covered the clad as well as the HAZ areas adjacent to the clad run. The travel speed during the heat treatment was varied between 1 mm/s and 5 mm/s. If the heat flow into the material is considered to be one dimensional, the laser interaction times with these travel speeds varied between 1.6 s and 8 s for the 8 mm spot size and 2.4 s and 12 s for the 12 mm spot size. The heat treatment temperature was set at either 700 °C or 800 °C, seeing that the $Ac_3$ temperature for the three substrates is 853 °C, 851 °C and 780 °C respectively. These high set temperatures were chosen with the aim of executing the heat treatment as quickly as possible.

The as-welded and heat treated single clad tracks were transversely cut, in an area where the temperature stabilised, and then mounted and polished. The HAZ areas were analysed by conducting hardness traverses from the clad metal down into the substrate material, as well as sub-surface traverses across the HAZ and dilution areas. The as-welded clad tracks were analysed to determine the baseline HAZ hardness for the different substrate materials. Clad track cross-section micrographs were taken to support the hardness result findings in terms of the heat treatment area either sufficiently covering the whole HAZ area of the clad, or not.

Table 2. Cladding parameters used for all the different substrates.

| Substrate material | Travel speed [m/min] | Powder flowrate [g/min] | Laser spot size [mm] | Carrier gas flowrate (Ar) [l/min] | Power [kW] |
|---|---|---|---|---|---|
| 21CrMoV5-11 / X22CrMoV12-1 / 34CrNiMo6 | 1.5 | 17 | 3.5 | 1.5 | 4.4 |

Table 3. Local heat treatment parameters applied to the single clad tracks.

| Substrate material | Travel speed [mm/s] | Spot size [mm] | Set temperature [°C] | Power [kW] |
|---|---|---|---|---|
| 21CrMoV5-11 / X22CrMoV12-1 / 34CrNiMo6 | 1 & 5 | 8 & 12 | 700 & 800 | Pyrometer control |

## 3. Results and Discussion

### 3.1. Hardness

The clad tracks and heat treatment runs done on the three different substrates are shown in Fig. 2. With the travel speeds used and the laser power limited to 1.7 kW, some of the heat treatment runs did not reach the set surface temperature over the short distance travelled. Unexpected HAZ hardness results were obtained in these cases.

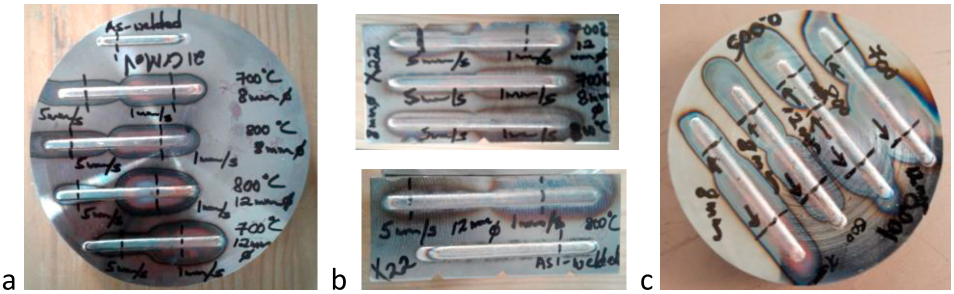

Fig. 2. Single clad tracks and heat treatment runs on a) 21CrMoV5-11, b) X22CrMoV12-1 and c) 34CrNiMo6 substrates.

The sub-surface hardness traverses across the HAZ and dilution area and the hardness traverses from the clad metal down into the substrate are shown in Fig. 3. From these graphs the following was observed:

- 21CrMoV5-11: The average as-welded HAZ hardness was 475 HV and the width of the HAZ approximately 400 µm. All the 800 °C heat treatments sufficiently lowered the HAZ hardness down to an acceptable level (below 400 HV), except the 2.4 s interaction time run during which the surface temperature only reached 560 °C due to the short cycle over the too short distance traveled and the limited power of 1.7 kW.

  The 700 °C heat treatment runs did not result in sufficient lowering of the HAZ hardness, except for the 12 s interaction time run. The insufficient lowering in hardness was either due to the set temperature being too low or too low temperature – interaction time combination, because the set temperatures were all reached during the heat treatment runs.
- X22CrMoV12-1: The average as-welded HAZ hardness was 560 HV and the width of the HAZ about 500 µm. The local heat treatments done at these parameters were not very successful in lowering the HAZ hardness to below 400 HV. The only successful treatment done was at 800 °C with the maximum studied interaction time of 12 s. Longer interaction times at 800 °C or a slightly higher set temperature can therefore be investigated, as long as it does not exceed the $Ac_3$ temperature of 851 °C.
- 34CrNiMo6: The average as-welded HAZ hardness was 600 HV with a width of about 600 µm. The heat treatment done at 700 °C with a 12 s interaction time resulted in the lowest HAZ hardness of 373 HV. The rest of the 700 °C heat treatments were not effective enough in lowering the HAZ hardness below 400 HV.

  The heat treatments done at 800 °C with interaction times of 1.6 s and 8 s also resulted in satisfactory HAZ hardness. The 800 °C treatment with 2.4 s interaction time did, however, not reach the set T (only reached 670 °C) and since the temperature was close to 700 °C, the hardness obtained was similar to that of the 700 °C treatment with the same interaction time. The 800 °C treatment with an interaction time of 12 s resulted in similar HAZ hardness as for the as-welded condition. This was due to partial austenitization during treatment and since the typical cooling rate is very high, martensite formed in these areas upon cooling. The austenitization at 800 °C for the longer interaction time have occurred due to the $Ac_3$ temperature of this substrate being 780 °C.

### 3.2. Microstructure

Some stereo micrographs are shown in Fig. 4 and depict the HAZ and heat treated zones. Both the 8 mm and 12 mm spot size treatment runs covered the whole HAZ area all around the single clad tracks on all three substrates. The maximum obtained heat treatment zone depth was typically 1 mm, which is in accordance with literature.

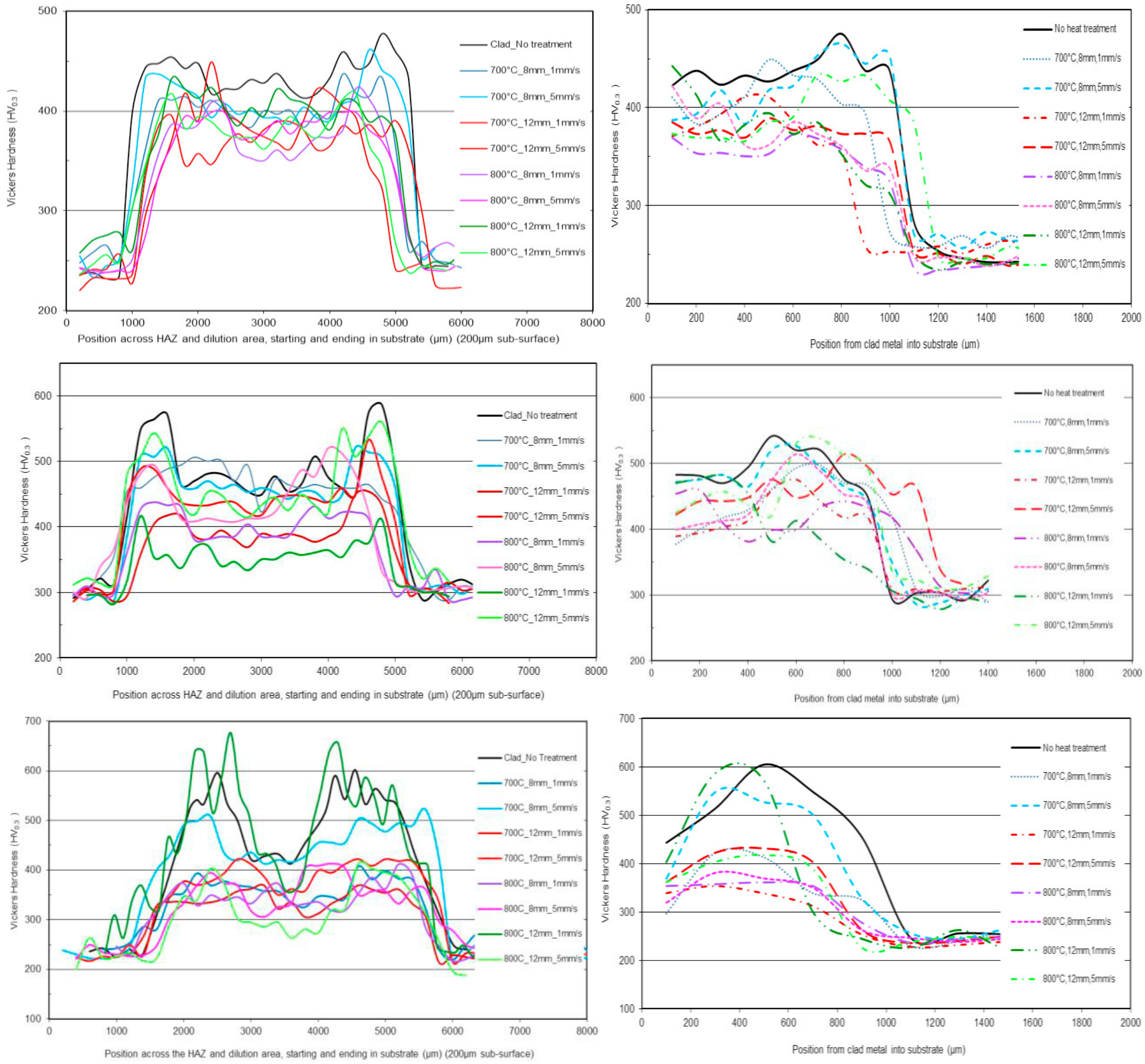

Fig. 3. Sub-surface hardness traverses (left) and transverse hardness traverses (right) obtained on 21CrMoV5-11 (top), X22CrMoV12-1 (middle) and 34CrNiMo6 substrates (bottom)

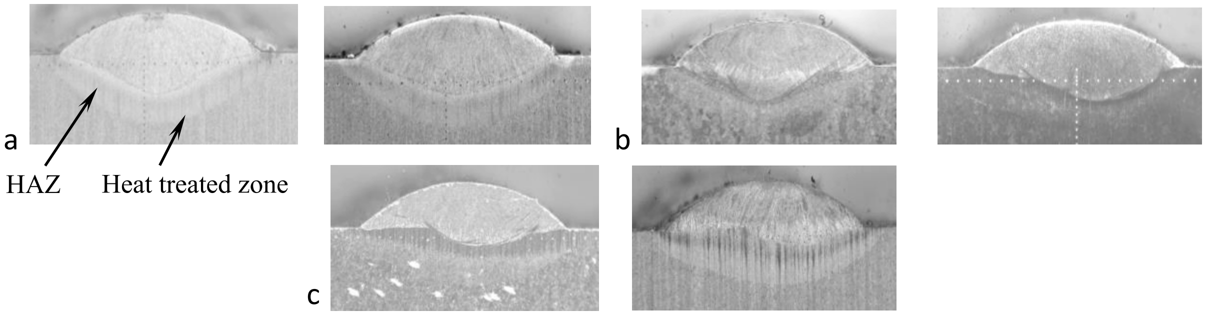

Fig. 4. Stereo-micrographs of heat treated single clad tracks on (a) 21CrMoV5-11; (b) X22CrMoV12-1; (c) 34CrNiMo6. For all three substrates the 8 mm spot Ø heat treatment is on the left and the 12 mm spot Ø one on the right. All these were done at the same set temperature.

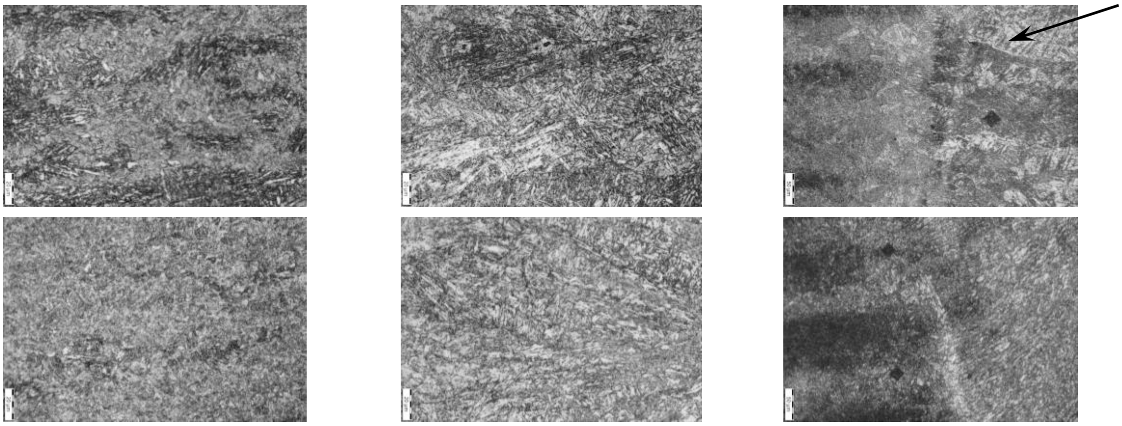

Fig. 5. Optical micrographs of the cladded 34CrNiMo6 substrate, locally heat treated for 12 s at 800 °C (top) and at 700 °C (bottom) respectively.

Optical microstructures at various positions of the cladded 34CrNiMo6 material, heat treated at 800 °C for 12 s were compared to that heat treated at 700 °C for 12 s (Fig. 5). Areas containing fresh martensite can be detected in the microstructure of the material treated at 800 °C (indicated by arrow) versus the expected tempered martensitic structure of the 700 °C heat treated sample.

## 4. Conclusions

- For 21CrMoV5-11 material, the local post-weld heat treatments at 800 °C resulted in sufficient lowering of the HAZ hardness from an average of 475 HV down to all below 400 HV.
- Cladding onto the X22CrMoV12-1 material resulted in an average HAZ hardness of 560 HV. This material showed the highest resistance to the local PWHT and only one heat treatment successfully lowered the hardness.
- The average as-welded HAZ hardness measured on the 34CrNiMo6 material was 600 HV and the local heat treatment done at 700 °C with a 12 s interaction time resulted in the lowest HAZ hardness of 350 HV. The same interaction time at 800 °C resulted in no decrease in hardness due to austenitization of the as-welded structure and the formation of fresh martensite during the rapid cooling.
- The feasibility of local laser post-weld heat treatment on all three substrates have been proven and may result in a faster, more cost-effective solution for specific laser cladding applications. The spot size and available laser power are the limiting factors on the treatment cycle times and the combination will have to be optimized.
- Future work should involve additional heat treatments done on X22CrMoV12-1 to determine an operating window for the local heat treatment instead of having only one parameter set.
- Single clad layers on all three substrates should also be locally heat treated to investigate the additional effect of multiple tracks on the HAZ hardness.

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