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Laser welding of heat treatable steel during induction hardening

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Abstract:

At the Laser Zentrum Hannover e.V. a new welding process was researched: Heat treatable steel is welded with an Nd:YAG laser while it is heated inductively. This combined process reduces production time because the heat energy of the induction hardening can be used for preheating the specimen before welding. The layout of the combined processing head is shown in fig. 1. The combined processing head consists of an integrated inductor, a laser processing head, and a shower. This head combines two work steps: inductive hardening and laser welding. The work piece is heated inductively to austenite temperature (approximately 900 °C). In this preheated part of the specimen the laser welding process is carried out. After quenching the work piece, the heat affected zone and welded seam do not show cold cracks. The heat affected zone and welded seam have almost the same material properties. This part of the work piece can be used as a functioning surface.

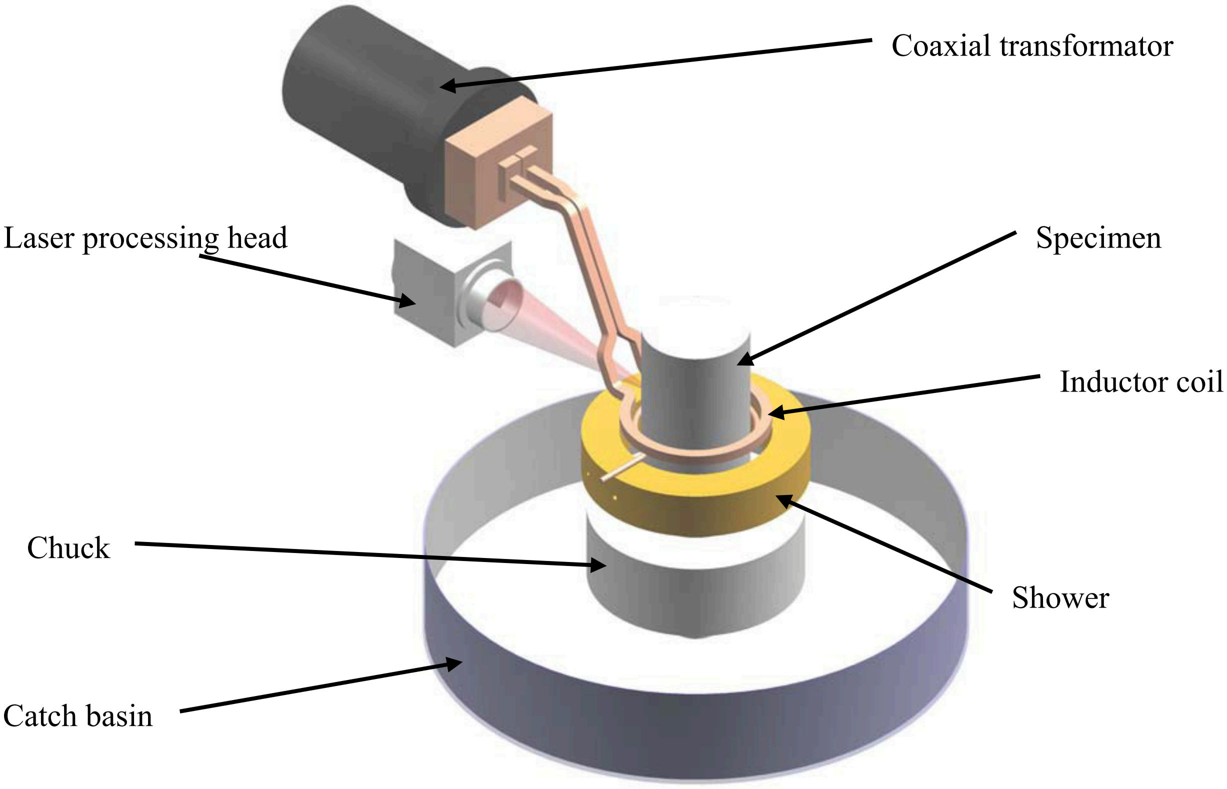


Fig. 1. Schematic experimental setup with combined process head

1. Introduction and motivation

Tempered steel can be heat treated because of its chemical properties. In a tempered condition, this steel has high hardness with a defined tensile strength. Components made of tempered steel are heat treated depending on their usage. Usually the heat treatment implies hardening and tempering. Tempered steel has a carbon content of 0.2 % to 0.65 %. The temperature for tempering has to be at least 500 °C or more, depending on the material properties needed. The main applications for components made out of this steel are high strain components such as gears, spindles, camshaft etc. [1, 2, 3].

Laser welding heats the base metal to high temperatures much faster than gas metal arc welding does. Because the energy input per unit length is very small, the volume of the melt pool is small as well, and it cools down quickly. The critical cooling time between 800 °C and 500 °C is very short. Even steel with a carbon content between 0.1 % and 0.2 % tends to develop a martensitic microstructure, which is hard and runs a high risk of crack formation. To avoid this fast cooling, the component has to be preheated before welding [4].

The manufacturing process for gears, spindles, camshafts, etc. is generally very complex. After heat treatment before laser welding, these parts have to be preheated to avoid hardening or crack formation. When welding is finished, the parts have to be tempered. This whole process is energy inefficient, and requires transportation between the process stages [5, 6].

These processes can be combined to a single process stage. This new process is a combination of heat treatment, laser welding and optional surface hardening, and it offers many advantages: Before welding, the component is heated to a temperature of approximately 900 °C. Since the component does not have to be preheated separately, production time can be decreased. Furthermore, the material in the heat affected zone and the welded seam show the same material properties in hardening and microstructure. Therefore, crack formation can be reduced to a minimum, and it is possible to use the welded seam as a functioning surface. This process can be used for manufacturing gears, spindles, camshafts, etc .

2. Experimental setup

The specimens were manufactured out of CF53 and 42CrMoS4. For the first test series a diameter of 100 mm and a height of 120 mm were chosen. For fundamental process development a bead on plate welded seam was chosen. It was 35 mm below the top of the specimen (see Fig. 2).

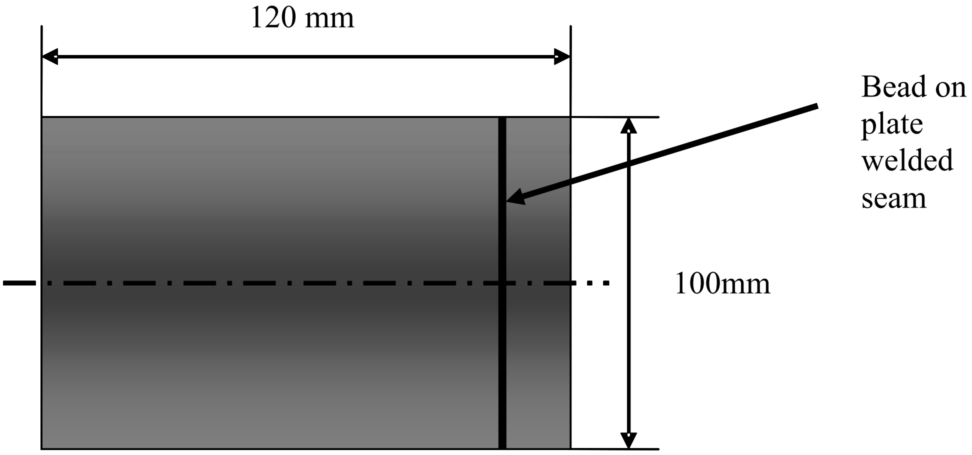


Fig. 2. Diameter of the specimen

Because the process head (see Fig. 3) is designed very compact, it is possible to integrate it into already existing inductive hardening equipment. The process head consists of a laser welding head, a shower, an inductor coil and a coaxial transformator.

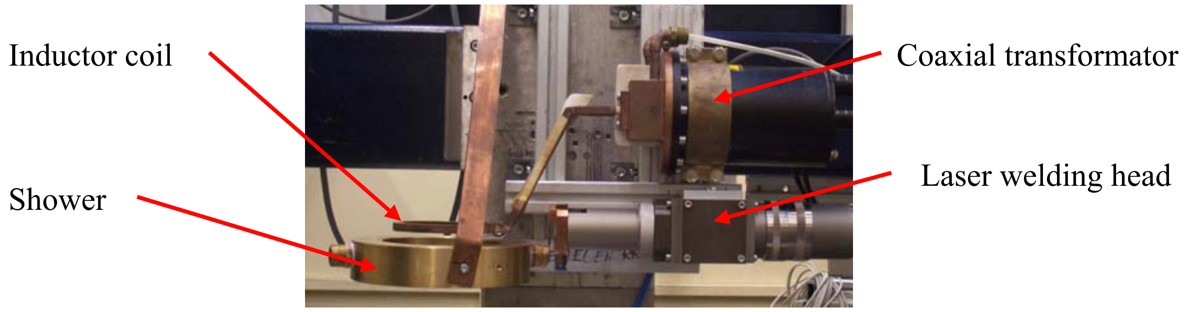


Fig. 3. Combined process head

This process head is part of the test setup (see Fig. 4). Above the process head a pyrometer is mounted. It measures the temperature in the heated zone on the surface of the specimen 10 mm away from the welding spot. The specimen is held by a chuck. Beneath the chuck is a basin to collect the cooling liquid, which is lead through a conduit pipe to a water tank. On top of the water tank is a pump, which supplies the shower with cooling liquid.

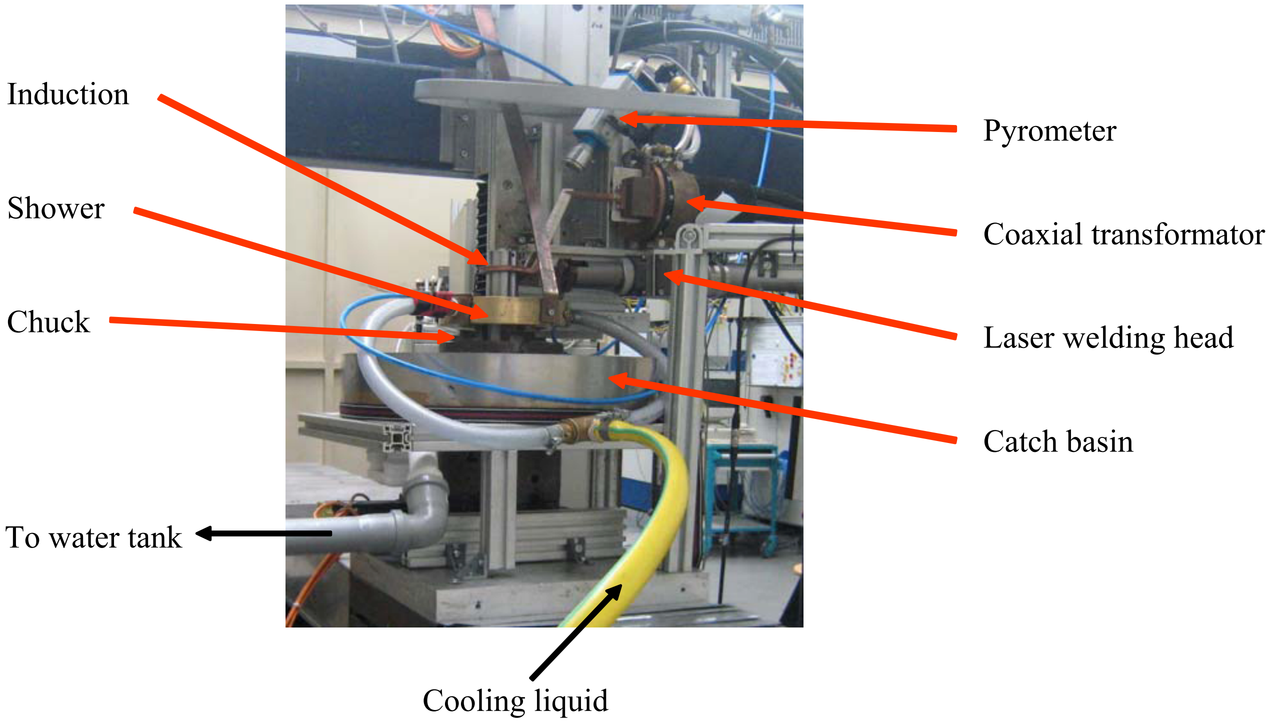


Fig. 4. Experimental setup with combined process head

With this setup several adjustments can be made:

- The power output of the laser can be adjusted from 0 to 4 kW and was set to 4 kW.
- The output of the inductor can be regulated to a maximum of 44 kW and was controlled by the temperature measuring device.
- The time for preheating can be adjusted as needed and was set between 10 s and 60 s.
- The welding speed can be adjusted from 0.5 m/min to 4 m/min.
- The time for showering the specimen with cooling liquid can be adjusted as needed and was set to 45 s.

The first step of the combined process was inductive heating of the specimen in the welding zone to a temperature of 900 °C. After the part was welded in this area it was quenched with a shower to a temperature below 100 °C. For further experiments it is also possible to harden the surface of the part after welding by moving the inductor coil across the surface.

3. Results

With the described test setup a temperature above 900 °C on the surface of the specimen was reached after 7 seconds. Through the whole process (preheating and welding) the output power of the inductive generator was controlled with a pyrometer combined with temperature measuring device. Because the temperature was measured 10 mm ahead of the laser welding spot the temperature during the whole process was around 900 °C (see Fig. 5). For this specimen a preheating time of 30 s and a welding speed of 1 m/min were chosen.

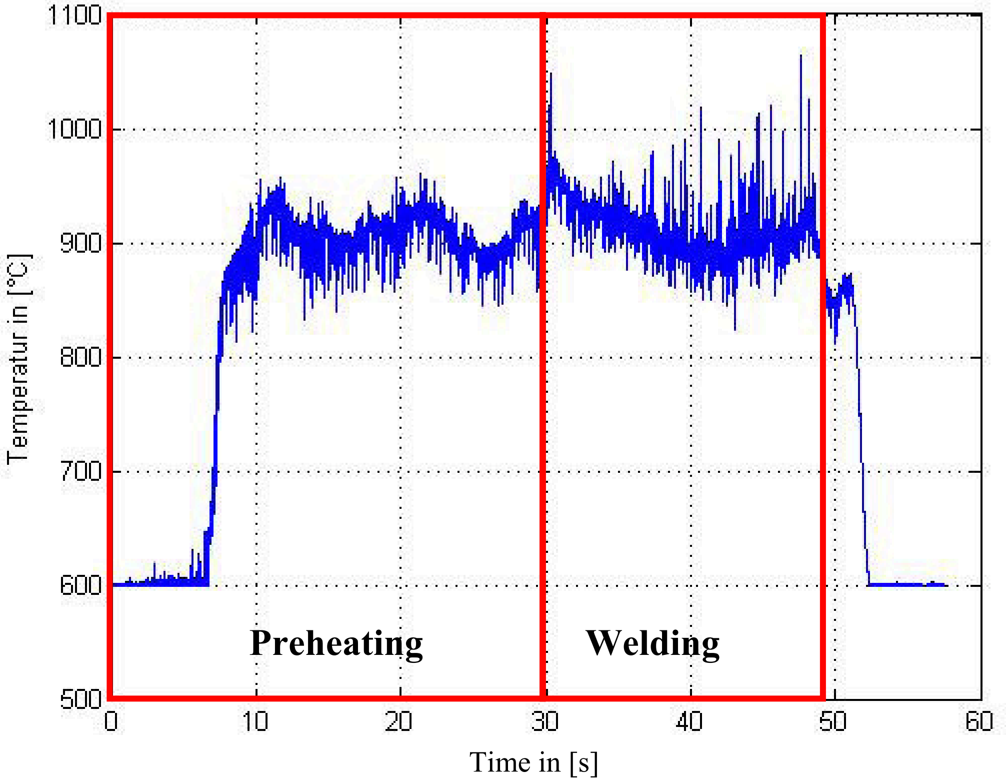


Fig. 5. Temperature profile during the process measured 10 mm ahead of the welding spot

Fig. 6 shows three different cross sections which were manufactured differently. The cross section on the left side (A) was made using the laser only. The welding speed was set to 1 m/min, which makes a welding depth of about 6 mm possible. Except for the welded seam there is no heat affected zone visible. The cross section in the middle seam (B) was welded with the same speed as the left one. Because this specimen was preheated the heat affected zone is much bigger and the penetration depth increased to approximately 7.6 mm. In addition, there is a great visible difference between the heat affected zone and the welded seam. The third part on the right side (C) was heated before welding and was quenched afterwards. Penetration depth is also about 7.6 mm. The structure of the cross section shows no remarkable difference between the heat affected zone and welded seam.

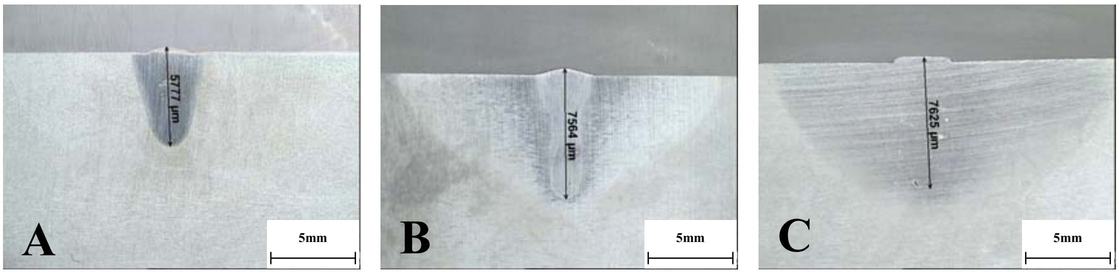
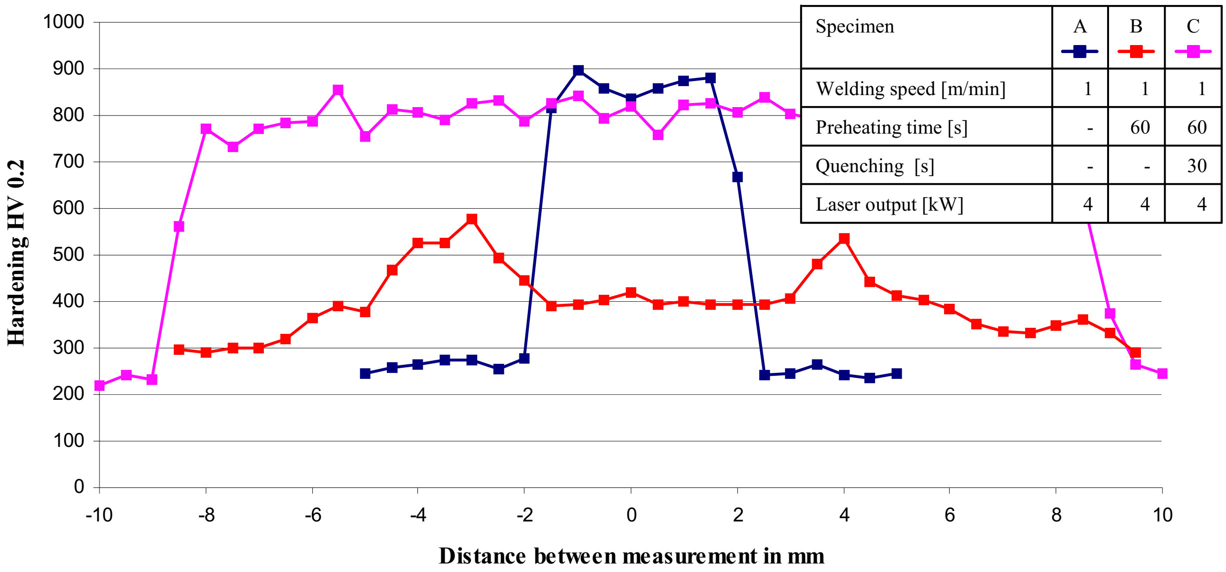


Fig. 6. Cross section of welding seams: left (A): laser welding only, middle (B): preheating and laser welding, right (C): preheating, laser welding and quenching

These three welded seams show different properties regarding the microstructure and hardening. The hardening measurement took place 0.5 mm under the surface of the specimen. The laser welded seam without any heat treatment (left) is 3.5 mm wide and the hardness is about 900 HV 0.2. This seam shows crack formation and therefore cannot be used as a functioning surface. The second seam (middle) was manufactured by preheating before laser welding. Because the specimen was not quenched hardness on left and right side of the seam reaches a maximum of about 550 to 580 HV 0.2 which can lead to crack formation during load. The rest of the specimen has a hardness between 300 and 400 HV 0.2. The third specimen (right) was treated with the combined process. There is no difference in hardness between the welded seam and the heat affected zone. The hardness is approximately 800 HV 0.2. This part of the specimen can be used as a functioning surface.



Specimen	A ■	B ■	C ■
Welding speed [m/min]	1	1	1
Preheating time [s]	-	60	60
Quenching [s]	-	-	30
Laser output [kW]	4	4	4

Fig. 7. Hardening measurement of three different heat treated specimen

4. Conclusion and outlook

The combination of inductive heating and laser welding was successful. The welding seam and the heat affected zone show the same material properties after quenching. Because there is no crack formation the heat influenced zone can be used as a functioning surface. Compared to the laser welding process without preheating welding depth could be increased approximately 2 mm. In addition the combined process saves production time. It takes only up to 2 minutes.

Further experiments will be performed on a specimen with other dimension. The diameter of this specimen will be 50 mm instead of 100 mm and it will consist of two parts. This new specimen will also be surface treated to harden the surface of the whole part in feed after welding. For these experiments a PLC (programmable logic controller) will be integrated into the test setup. Instead of the temperature measuring device which controlled the inductive generator the PLC will control it based on the pyrometer data. For better welding results a shielding gas nozzle will be integrated as well.

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