Mechanical and Metallurgical Effect on Tubular Shape by Laser Forming

Mahmudun Nabi Chowdhury, Ju-Ri Kim

Abstract— ***Mechanical properties of indirect hot stamping tubes are tailored by laser assisted partial rapid heating. A spiral heated region is generated on a rotating hot stamping steel tube by applying linearly moving laser. A microstructural analysis confirms that martensite phase transformation is occurred in the spiral heated region, thus inducing inhomogeneous microstructures along the length. Mechanical tests show that the mechanical performance of the indirect hot stamping tube can be tailored by properly selecting process parameters of the laser assisted heating. A microstructural analysis confirms that the laser locally induces a martensitic phase transformation in the heated region and results in inhomogeneous microstructures along the length of the tube.***

Index Terms— indirect hot stamping, laser assisted heating, mechanical property.

I. INTRODUCTION

Due to the demand for reduced vehicle weight, improved safety and crashworthiness qualities, increasing hot stamping parts are used for automobile structural components from ultra-high strength steel [1]. The hot stamping process currently exists in two different main variants: the direct hot stamping and the indirect hot stamping method. The full martensitic parts are characteristic of high strength (1500 - 1700 MPa) and poor ductility generally less than 5%. Therefore, generally high strength steel hot stamped parts are not satisfactory for the energy absorbing parts of automobiles [2]. However, with the more widespread application of high-strength steel, the compatibility of mechanical properties and safety performance of vehicle parts has been proposed that different mechanical properties are needed in different regions of the same parts, namely tailored properties. Many scholars have carried out a series of studies on how to realize the tailored mechanical properties of the hot stamping parts. This paper focuses on the effectiveness of tailoring properties for indirect hot stamping tubes during LASER heat treatment specially. The progressive interest in safety and crashworthiness of structures has led to a wide ranging research on the crashing responses of thin-walled tube which is made by the cold drawing process. This tube structures have been widely used as key components in automobile and aerospace industry with goal to improve crashworthiness and safety of vehicles while maintaining overall light-weightiness [3]. Different geometries of tubular shapes such as circular, rectangular, square, tapered, hat-section and cone, are known as excellent impact energy absorbers due to their ability to deform in a stable, Progressive axial manner [4]. These tubes are used as different parts of the automotive body such as: shock absorber, steering system, seats construction and chassis components of automobile’s construction to enhance the crashworthiness during collisions. Despite its thinness, thin wall tubing still provides insulation and strength accordingly as well as carrying many advantages like light weight, low cost and so on. Studying the crashworthiness of thin-walled tubes subjected is relatively new. However, manufacturers are trying to improve the absorbed energy of tube in different ways. Three point bending test is one of the methods that figures out the improvement of absorption of energy of tube. In order to investigate the development of absorbed energy or strength of hallow shape tubes through bending test many studies have been worked on. They concluded that filling of foam improved the load carrying capacity by offering additional support from inside and increased the energy absorption. It was also pointed out that partial filling of foams increased the energy absorption to weight ratio of the structure [5, 6]. This paper focused on improving the absorbed energy or load carrying capacity of hot stamping tube by laser assisted partial heating with maintaining tailored mechanical properties. Various theories have been proposed to explain the mechanism of expanding the absorbed energy by bending collapse of tube. Even though those theories suggest different mechanism for increasing the load carrying ability of tube by filling full or partial anisotropic material (i.e. fiber reinforced composite materials, natural wood and wood products, and mammal bones, among others) into empty tubes. At present LASER for material processing is developed that allows a flexible and local heat treatment. However, it also needs to be noted that by LASER assisted heating it is possible to heat locally with maintaining tailored mechanical properties. In recent years Laser technology has become quite spread in industry thanks to a number of advantages it has in comparison with conventional heating technology. The result of LASER heating process is affected by properties of thermal conductivity, power density distribution of LASER thermal source and shapes and mass of materials [7, 8]. Generally, research on LASER heating process has been carried out on plain surface for partial heating to strengthen for particular shapes like rectangular [9 -11]. To maintain the tailored properties on rectangular shape, electrically assisted heating has many advantages in comparison with LASER heating [12, 13]. In principal, also technologies based on heat induction and heat conduction could be used for tailoring the

Revised Version Manuscript received on June 22, 2016.

Mahmudun Nabi Chowdhury, Department of Mechanical Engineering, Advanced Engineering Materials Laboratory, University of Ulsan, Ulsan (South Korea). East Asia.

Jur-Ri, Kim, Department of Mechanical Engineering, University of Ulsan, Ulsan (South Korea). East Asia.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

mechanical properties. Moreover, one clear dis-advantages of electrically assisted heating for tubular shape in a commercial manufacturing process is that proper way of local heating with maintaining the tailored mechanical properties[14-20]. Therefore, an alternative process is that applying rapid LASER heating linearly during the rotation of hot stamping steel tube. By this way spiral shape heated region will occur partially over the whole surface of tubular body which may has its own unique features in comparison with conventional heating (furnace) process of tube. In this study we also examine improved mechanical properties after LASER heat treatment and also rule of mixture is detailed for the description of the tailoring properties.

II. Literature Review

A. *Laser Forming Technology*

Laser in manufacturing is further classified into two main categories namely (a) laser forming and, (b) laser assisted forming. In laser forming, the final shape of the part is obtained by the exclusive use of the laser technology, eliminating other operations of the traditional forming. On the other hand laser assisted forming combines the features of both the laser forming and the traditional forming operations. On the other hand laser assisted forming combines the features of both the laser forming and the traditional forming operations.

Laser forming (Fig. 1) is one of the newer forms of unconventional form of shaping a metallic or a non-metallic material. In this process, work piece, usually in the form of sheets, is deformed into a desired shape by irradiating the surface using high powered laser beam. This leads to development of thermal stresses especially near the heated area. The work piece expands and when it is restrained by the surrounding material localized plastic deformation takes place. On cooling, the bending takes place towards the laser beam. The desired shape of the work piece is achieved by controlled plastic and elastic deformation. Figure 1 shows the overview of the laser forming process. Laser forming is different when compared to the traditional forming techniques like drawing, stamping, pressing, etc. in the sense that it is a non-contact technique. Also, it is a highly flexible and low-volume manufacturing process. Laser forming can also be used for cutting, welding, and drilling operation by changing the processing parameters. It is used to deform sheets of various metals e.g., stainless steels, aluminum alloys, magnesium alloys etc., which have high coefficient of thermal expansion. Also, many hard and brittle materials, such as titanium and nickel alloys, ceramics, glass, semiconductors, etc. also can be formed with little distortion or degradation. There are some advantages of Laser forming/laser assisted forming:

- Flexible forming processes
- Precise deformation can be achieved because spring-back behavior is not involved which is related
to the quality of product.
- Forming is available in inaccessible areas
- Brittle, hard and thick material can be processed.

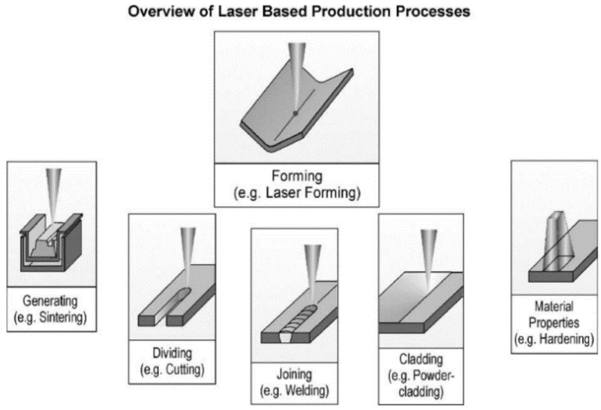


Figure 1. Laser forming process

B. *High Strength and Toughness Tubes*

The world nowadays is emphasizing on issues that deal with sustainability and economical energy. As a result, this trend brings to material saving policy and thin wall tube became more and more important structural element that is used in structural design and daily application. The aim of this project is to study the properties of thin wall tube under static loads.

Thin wall tubes are important structural elements that have vital application in many engineering aspects such as automobile, aerospace, construction and piping systems Fig. 2. Despite its thinness, thin wall tubing still provides insulation and strength and is commonly used in medical and aerospace applications.

The progressive interest in safety and crashworthiness of structures has led to a wide ranging research on the crashing responses of thin-walled tube which is made by the cold drawing process. This tube structures have been widely used as key components in automobile and aerospace industry with goal to improve crashworthiness and safety of vehicles while maintaining overall light-weightiness. Different geometries of tubular shapes such as circular, rectangular, square, tapered, hat-section and cone, are known as excellent impact energy absorbers due to their ability to deform in a stable, progressive axial manner. These tubes are used as different parts of the automotive body such as: shock absorber, steering system, seats construction and chassis components of automobile’s construction to enhance the crashworthiness during collisions. Despite its thinness, thin wall tubing still provides insulation and strength accordingly as well as carrying many advantages like light weight, low cost and so on. Studying the crashworthiness of thin-walled tubes subjected is relatively new. However, manufacturers are trying to improve the absorbed energy of tube in different ways. In order to investigate the development of absorbed energy or strength of hallow shape tubes many studies have been worked on. A comprehensive study on the deep bending collapse of thin-walled rectangular columns was first carried out by Kecman and a simple failure mechanism consisting of stationary and rolling plastic hinge line was proposed. In order to investigate the potential for further structural weight savings, the earliest researches into the bending of aluminum foam-filled hollow sections were given by the numerical work by Santosa and Wierzbicki and the experimental work

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

by Santosa et al. They concluded that filling of foam improved the load carrying capacity by offering additional support from inside and increased the energy absorption. It was also pointed out that partial filling of foams increased the energy absorption to weight ratio of the structure. This paper focused on improving the absorbed energy or load carrying capacity of hot stamping tube by laser assisted partial heating with maintaining tailored mechanical properties.

Figure 2. Tubular shape application in automotive body

III. EXPERIMENTAL PROCESS

In the present study, the tubes were made of medium carbon steel used as a specimen in this experiment. The chemical composition with other specifications of selected material is was observed. We cut the specimen in 200 mm long for both rapid heating and mechanical testing. The wall thickness of the tube was 2 mm and the diameter of the tube was 25.4 mm accordingly. The amount of carbon content was 0.5% (mass fraction). Experimental set up was composed of 4 kW-Class CW Nd:YAG LASER and a Gaussian beam profile, a 7-axis control arm robot and small size lathe (Mini lathe machine; DML140). A schematic of the experiment is shown in Fig. 3. The beam was applied by linear moving of LASER on specimen while it was rotated by the mini lathe.

In this experiment the linear speed of LASER (υ_L), LASER power (P) and circumferential speed of tube (ω_T) were suggested by dominant test matrix as major test parameters. As a result spiral heating lines were seen over the tubular steel.

Two different concepts of LASER assisted partial heating were examined respectively. First, the concept was examined by heating the tubes locally with the major test parameters where rotational speed was selected as the slowest speed of lathe (ω_{T1} = 2.74 rad/sec) and power of LASER was fixed at (P_1) 3.5 kW. Second, the similar concept was followed but just a little change in test parameters by decreasing 10% of the LASER power (P_2= 3.20 kW). For both concepts we had to choose some suitable linear speeds (υ_L) of LASER by trial and error methods to avoid the melting of tubes during heat treatment.

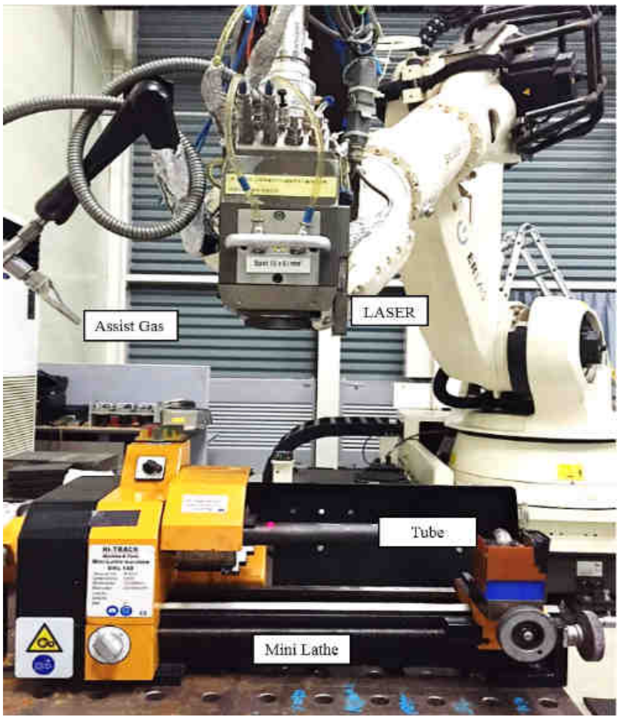


Figure 3. Experimental set up

However, after analyzing the result of these two different concepts of LASER heat treatment with conventional (furnace) heating, it is easy to figure out the change on absorbed energy of tubes by three point bend test. After rapid heating by LASER all tubes were quenched by cold water very fast for achieving the martensite phase transformation properly. During the rapid heating by LASER, the power distribution of fiber optic coupled high power diode LASER is close to top hat distribution was used in the model. To avoid melting of tubes, subsequent scans were carried out with LASER power reduction initially, i.e. 3.9 kW, 3.8 kW, 3.6 kW respectively. Axial heating length was 200 mm while the linear velocity of LASER was fixed at different speed (υ_L); i.e. 3 mm/sec, 3.10 mm/sec & 4 mm/sec subsequently. The temperature of the specimen during LASER assisted rapid heating was measured by a FLIRT621 infra-red thermal imaging camera (FLIR, Sweden) for observing the austenite temperature of steel. The material is assumed to be homogeneous and isotropic. The ambient temperature was set at 20°C. Moreover, to compare the result with the conventional (furnace) heating this experiment was carried out by laboratory furnace testing “Nabertherm GmbH, Germany” that can raise temperature up from 30°C to 3000°C. The tubular steel specimens were subjected to three point bending tests for measuring the change of absorbed energy after heating. A custom made fixture as schematically shown in Fig. 4 was designed and installed in a universal testing machine (Daekyoung, South Korea) for the experiment. The fixture was designed on basis of ASTM standard design. In this fixture the cross head diameter was designed on 60 mm (φ_1) and it has sufficient clearance between cross head (loading nose) and the supports. According to the ASTM standard methods the cross head (loading nose) diameter can be extended to 1.6 times of specimen’s diameter. On the other hand, 60 (φ_1) mm diameter of loading nose covers the maximum spiral heated line area

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

during compression so that the amount of absorbed energy can be investigated and distinguished with the base line test. The cross head (loading nose) strain rate was 2 mm/sec. The steel tube was placed in two cylindrical supports (φ_2= 25 mm) as shown in Fig. 4. Three point bending strength was measured with a constant span length of 100 mm. After heating all the tubes at austenite temperature range, tubes were quenched into cold water until the entire martensite transformation completely. For microstructural analysis, samples were observed from cross-sectional view. All microstructure observation were observed along the surface of cross-sectional direction of the specimen in terms of the specimen's depth and diameter. The observation of the surface was divided into 3 regions as LASER heat treated region, boundary region & base region.

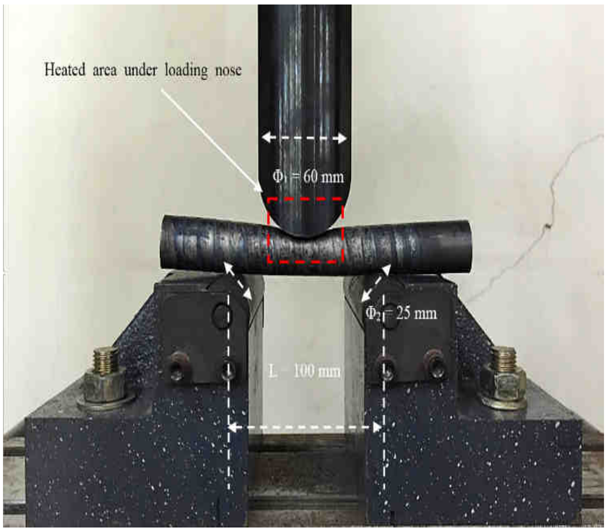


Figure 4. Three point bend test

IV. RESULT

A. *Effect of LASER Parameters on Heat Treatment*

The heat applied by LASER assisted rapid heating on material is affected by beam diameter (D_b), LASER power (P_L), rotating speed (ω_T) and LASER linear speed (υ_L). During the LASER heat treatment, process parameter was adjusted by following angular speed formula:

$$V_L=\omega_T r \qquad (1)$$

whereas, ω_T is the angular velocity or rotational speed of tube, V_L is the tangential or linear velocity of tube and r is the radius of the tube. However, for different test parameters we observed changes in mechanical properties of heat treated. Specimens were prepared by a standard metallographic grinding and polishing procedure, and finished with 1 µm diamond suspension followed by electro polishing tubes as well as mechanical test result too, especially by changing the LASER diode power (P) and different travel speeds (υ_L) of LASER because the rotation speed of tube was almost same for every test that makes the heat input almost constant. According to the first concept at 3.5 kW (P1) of LASER power we heated locally all tubes by different linear speeds (υ_L) as major test parameter. During this test the rotation speed was fixed at 2.73 rad/sec (ω_T).

First we heated rapidly the tube with 3 mm/sec of linear speed of LASER that was taken 54 seconds to heat axially of the tube. Subsequently by other two parameters of linear speed (υ_L) at 3.10 mm/sec and 4 mm/sec were tested to heat the tubes which were taken 51 seconds and 40 seconds respectively. Different heating angle (θ) was observed for helical heated lines which is already shown schematically in (Fig. 1). We investigated that higher tangential speed of LASER shows the higher heating line angle. Therefore, heating angle (θ) is calculated by vector calculation of linear speed (υ_L) of LASER and rotation speed (ω_T) of tube by lathe as follows:

$$tan\,\theta = {}^{\upsilon}/_{\omega r} \qquad (2)$$

By the increment of LASER speed we observed higher heating angle with wider distance too (Fig. 5) among the heated lines that suggests the boundary limit of homogeneous properties, accordingly. For LASER assisted partial heating two different properties are occurred on same part. We can investigate different unique homogeneous properties of same part that refers the tailored properties mainly. We checked the surface properly to be careful from melting of overheating by using magnifying glass

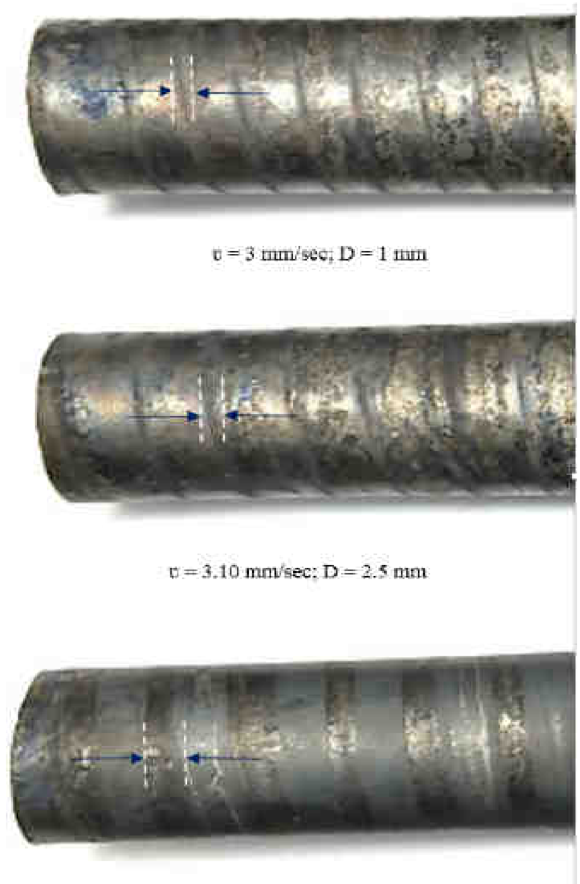


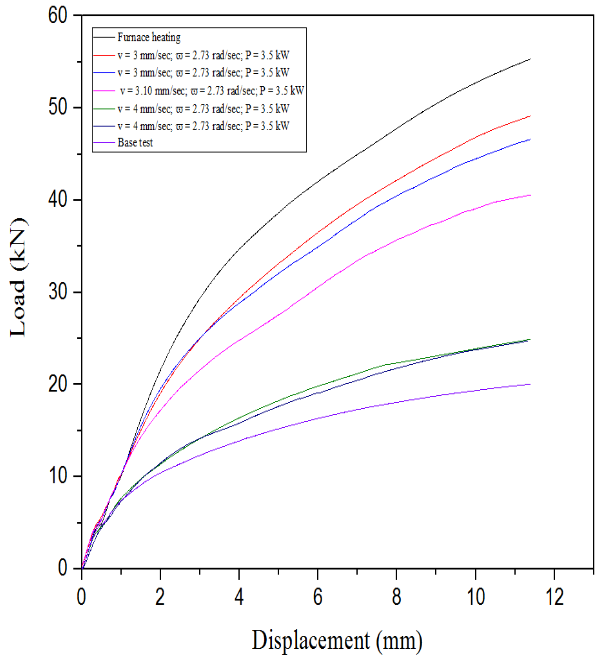
Figure 5. Distance (D) among heated lines

B. *Bending Test & Energy Absorption*

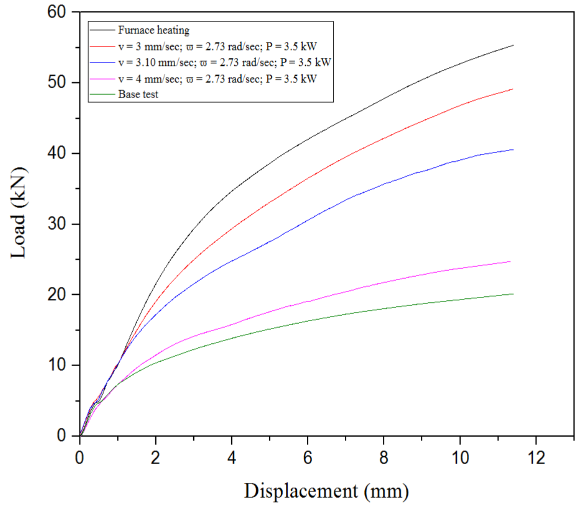
Three point bending test is one of the methods that figures out the ability of absorbed energy and change of bending strength of tubes. For the selected hot stamping steel tube, the bending strength after heating by different

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

LASER parameter is shown in Fig. 6 (a). The load displacement graph reveals that local heat treatment of tube increases the load carrying capacity significantly. For quasi-static loading, the load carrying capacity of unheated tube (base test) is the lowest and conventional (furnace) heat treated tube's capacity is the highest. In Fig. 6 (b) we see gradual increment of bending strength of different heat treated tubes by changing parameters of travel speed of LASER (i.e. 4 mm/sec, 3.10 mm/sec & 3 mm/sec).These parameters were tested under the same power input (P_1 = 3.5 kW) and rotation speed of tube (ω = 2.73 rad/sec). It proves that decreasing travel speed of LASER heating we can get higher bending strength gradually. However, heat treated tubes fail much earlier, especially heated by slowest travel speed of LASER though their load carrying capacity is relatively higher. Actually, the short term heat treatment leads to higher ductility of steel. Among the selected travel speed of LASER we chose 3.10 mm/sec and heated the tube with this travel speed of LASER under 10% lower power input (P2= 3.20 kW) and after carrying out 3-point bend test we observed lower bending strength with respect to higher power heated tube Fig. 5. As LASER power decreases the amount heat input decreases to heat the tube and as a result lower bending strength is observed in graph. We tested all bending tests to a certain distance at 11.4 mm (Fig. 6) and figured out the change of energy absorption ability for different heat treated tubes from the bending graph as well as compare those values with furnace heated tube too. The area under the load-displacement curve up to 11.4 mm represents the total energy absorption Fig. 7. shows the total energy of LASER assisted partial heat treated tubes by different parameters. Comparing all cases the total energy absorption ability of conventional (furnace)



(a)



(b)

Figure 6. (a) Change of bending strength of tube after local heating (b) Gradual increment of strength of heated tube by different LASER heating speeds

heated tube is the highest. Furthermore, we see the gradual increment of energy absorption of partial heat treated tubes by adjusting travel speed of LASER at 3.5 kW. These tubes have their own unique configuration, thus energy can be dissipated by retarding sectional collapse. Besides, Fig. 7 (b). shows the change of amount in absorbed energy ability for same LASER travel speed (3.10 mm/sec) due to power reduction. This indicates by changing the amount of LASER power can adjust the strength or energy absorption ability of tube.

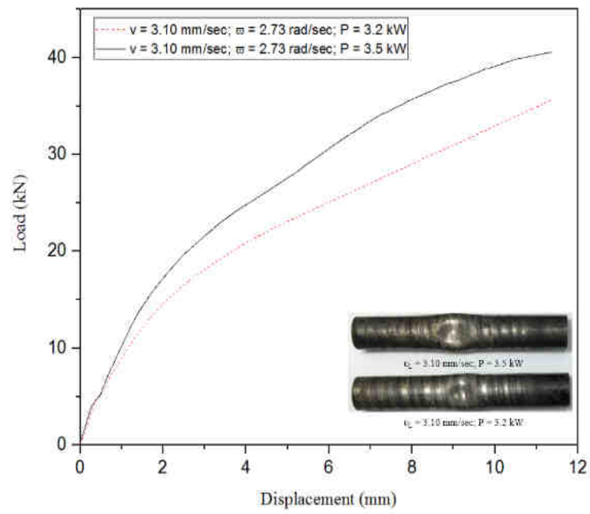


Figure 7. Bending strength development after laser heating

C. *Hardness distribution*

Hardness was measured to the longitudinal direction of heated tubes that was divided as LASER heat treated region, represents an average of three values measurement. Fig. 8 shows different angle of heated tubes by different laser speeds which is bend by three point bend test. Fig. 9 (a) and (b) show the absorbed energy in kJ by bar chart. Moreover, Fig. 10 (a) and (b) hardness distribution for different LASER

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

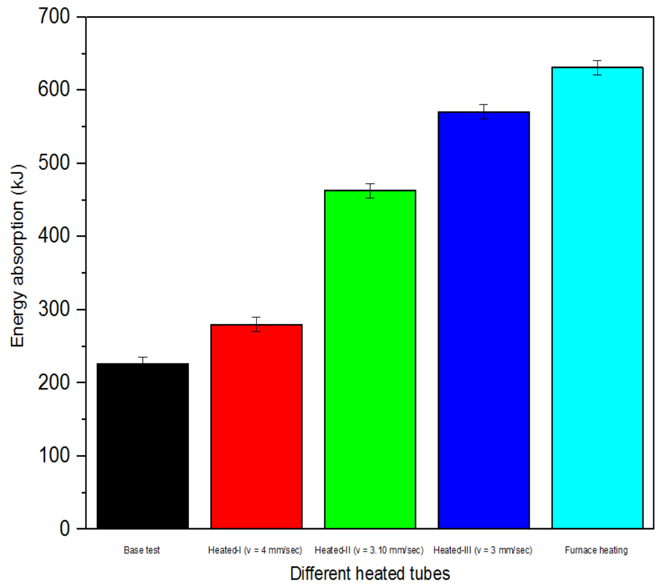
speed of heated tubes. For 4 mm/sec LASER speed and 3.5 kW power, boundary region (transition zone) and base region (between two heated helical lines). The hardness was tested by "Mitutoyo Vickers Hardness" machine. Each hardness data we observed the periodicity in hardness distribution that increases and decreases repeatedly in every segments. The heated zone and base region (between two heated helical lines) show their hardness maximum and minimum value 400HV and 150HV accordingly which is similar to the conventional (furnace) heat treated and unheated (base test) (Fig. 8 (b)). Boundary (transition) zone shows the diffraction of value within 350HV-290HV. We observed the diffraction at transition zone especially result for rotational speed of tube. For 3 mm/sec and 3.10 mm/sec of LASER speed we got higher Vickers hardness value in heated zone about 450HV in comparison with conventional heating.

Due to shorter distance among the heated lines for slower LASER speed (3 mm/sec & 3.10 mm/sec) we did not observe higher diffraction in hardness distribution at boundary (transition zone) and base region especially. Almost similar observation was found for 3.2 kW LASER power and 3.10 mm/sec LASER speed heat treated tube.

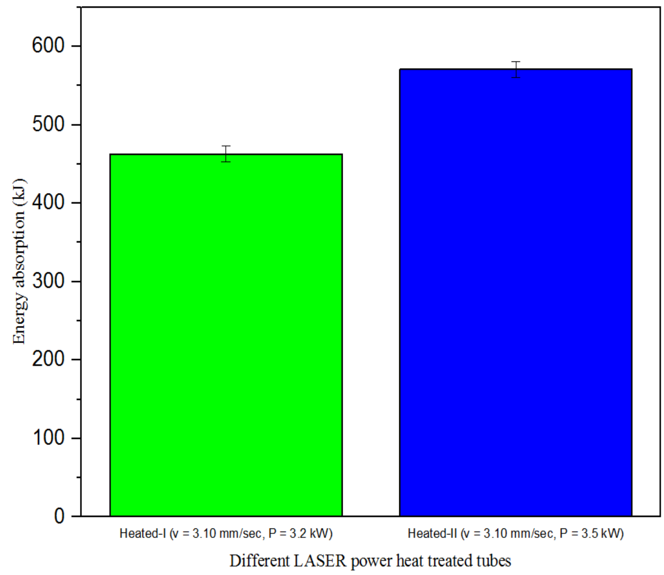
D. Microstructural Analysis

After LASER assisted heating of the tubes in austenite temperature range, the part is quenched by cold water properly until the entire martensite transformation completely. The image of regional microstructure in the hardened zone for different LASER speed heating parameters

Figure 8. Bend tested tubes



(a)

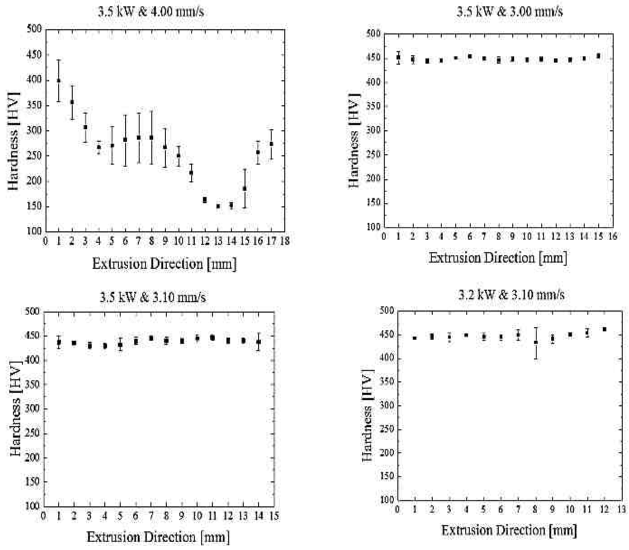


(b)

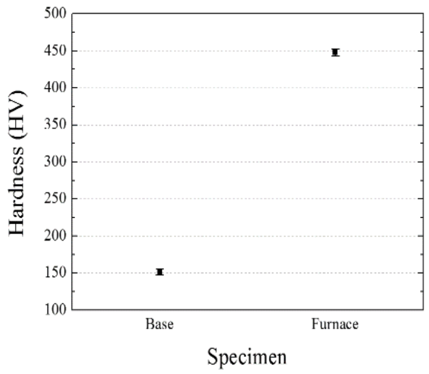
Figure 9. (a) Total energy absorption of different heat treated tubes by different LASER parameters. (b) Change in absorbed energy due to change in LASER power

is shown in Fig. 11 (a). After optical microstructural analysis it is ensured that the local heated area of the surface of tube for every heating parameters is transformed into martensite phase. The structure mixed with austenite and ferrite is observed in the interface between heated zone and the matrix shown in Fig. 11 (b). Additionally, the morphologies of these microstructural components are very different, and consequently their mechanical properties differ after heating. Therefore, the study of material macroscopic behavior becomes a difficult homogenization problem due to the fact that new phases continuously evolve.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

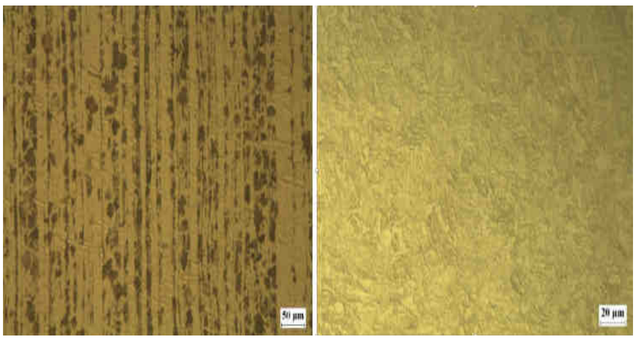


(a)

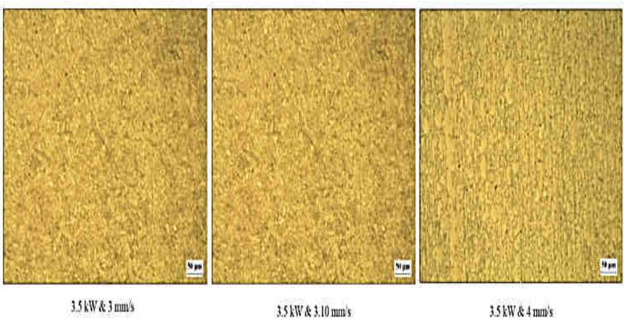


(b)

Figure 10. (a) Hardness distribution for different LASER speed. (b) Vickers's hardness of Base and Furnace heated tubes.



(a)



(b)

Figure 11. (a) Unheated and furnace heated surface OM view. (b) Surface OM view of different speed of LASER.

V. Conclusion

In the present study, the concept of tailoring the mechanical properties of a hot stamping tube by inducing a spiral heated region was successfully demonstrated via experiment. While mechanical tests show that the mechanical performance of the tube was tailored by properly selecting parameters of the laser assisted heating, the results of the microstructural analysis confirm that inhomogeneous microstructures were induced along the length of the tube as the result of local heating of the laser. The concept of a spiral heated region along the length of a tube also provides the technical advantage that the heat treatment process can be completed by a single cycle of the laser movement (or the tube movement if the laser is stationary), thus reducing the process time significantly. In general, the results of the present study suggest that the laser heating can be used as an effective local heating method after pre-forming during the indirect hot stamping process to tailor the mechanical properties of a part.

Acknowledgment

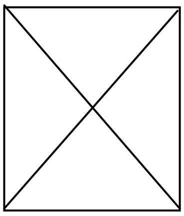
This work was supported by the University of Ulsan Research Fund.

References

1. Karbasian, H., Tekkaya, A., 2010. A review on hot stamping. Journal of Materials Processing Technology 210, 2103
2. Zhu, B., Zhang, Y., Li J., Wang, H., Ye, Z., 2011. Simulatio of hot stamping and phase transition of automotive high strength steel. Materials Research Innovations 15, 426
3. Lu G, Yu T. Energy absorption of structures and materials. Cambridge: Woodhead Publishing; 2003.
4. Nia AA, Hamedani JH. Comparative and deformations of thin walled tubes with various section geometries. Thin Wall Struct 2010
5. Vesenjak M, Krstulovic ´-Opara L, Ren Z, Öchsner A, Domazet Z ˇ. Experimental study of open-cell cellular structures wit material. Exp Mech 2009; 49:501
6. Belova IV, Veyhl C, Fiedler T, Murch GE. Analysis of anisotropic behaviour of thermal conductivity in cellular metals. Scripta Mater 2011; 65:436–9.
7. DAUSINGER F. Beam-matter interaction in laser surface modification [C]// Proceedings of LAMP'92. 1992; 697
8. WOO H G, CHO H S. Estimation of hardened flayer dimensions in laser hardening process with variations of coatings thickness [J]. Surface and Coating Technology, 1998, 102; 205
9. BENDOGNI V, CANTELLO M, CERRU W, CRUCIANI D, FESTA R, MOR G, NENCI F. Laser and electron beam in surface hardening of turbine blades [C]// Proceedings of LAMP'87. 1987: 567
10. READY J F. LIA handbook of laser material processing [M]. Laser Institute of America, 2001: 223-262.
11. CHEN T L, GUAN Y H, WANG H G, ZHANG J T. A study on austenite transformation during laser heating [J]. Journal of Material Process Technology, 1997, 63: 546
12. Standard Test Methods for Flexural properties of Unreinforced and Reinforced Plastics and Electrical Insulating materials; Designation: D 790-02.
13. Marion Merklien, Wolfgang Böhm material properties of aluminum by local laser heat treatment. Physics Procedia 39 (2012) 232-239.
14. S. K. Hajra Choudhury, A. K. HajraChoudhury, N. Roy, "Elements of Workshop Technology," Volume – I, Media Promoters and Publishers Pvt. Ltd. 2001.
15. G. E. Dieter, "Mechanical Metallurgy," SI Metric Edition, McGraw Hill, Singapore, 1988.
16. American Society for Metals. Committee on Induction Hardening, "Induction Hardening and Tempering," Metals Park, Ohio, American Society for Metals, 1964.
17. American Society for Metals. Committee on Induction Hardening, "Metals Handbook: Forging and Casting," Metals Park, Ohio, American Society for Metals, 8th Edition, Volume 5,1977.
18. S. Zinn, S. L. Semiatin, "Elements of Induction Heating: Design, Control, and application," ASM International, 1988.

19. K. Z. Shepelyakovskii, N.M. Fonshtein, V.P. Devyatkin, A. N. Mirza, B. K. Ushakov and B. O. Bernshtein, “Strength Characteristics of High-Carbon Steel with Controlled Hardenability After Bulk-Surface Hardening,” Volume 18, Number 5, New York , Metal Science and Heat Treatment, May, 1976, pp. 439-442.
20. K. Z. Shepelyakovskii, “Heat Treatment of Steel with Induction Heating,” Volume 19, Number 10, New York, Metal Science and Heat Treatment, October, 1977, pp. 909-916.

Mahmudun Nabi Chowdhury is perusing M.Sc. in Mechanical Engineering from University of Ulsan, South Korea. His main research interest in advanced materials science and engineering.



Ju Ri Kim is perusing M.Sc. in Mechanical Engineering from University of Ulsan, South Korea. His main research interest in Friction welding and materials characterization.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.