Standardization of laser marking for tracking gas pipes in transmission and distribution projects by destructive and nondestructive tests.

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Abstract

Gas pipelines need to be traced due to the sensitive usage and the number of involved pipe mills. In present research, implementation of laser engraving for marking API 5L pipes is standardized. Through an automatic process, this method of marking creates durable and high quality marks. For this purpose, technical specification of laser marking based on minimum requirements of traceability have been reviewed to obtain permanent marking without any effect on performance characteristics of gas pipes and its structural properties. After ensuring the acceptance of the process in the standards, initial samples have been engraved to find the appropriate laser characteristics, required to have adequate material removal and visible mark on the test pieces. Evaluation of gas pipe characteristics was performed based on operational condition of them in transmission and distribution network. All destructive and nondestructive tests were considered for test method and acceptance criteria were proposed in this point of view. Corrosion assessment tests were supposed for life test of pipes after engraving. Depth gaging, visual check for testing uniform engraving and suitable font and absence of sharp corners are some routine tests. All circumferential welds should be tested based on implementation codes; in this point of view in tracing pipes laser marking has its effect on radiography films that could be referred as a permanent document. Analyses are performed for two simultaneous outputs in order to reach the deepest engraving in the shortest time. To validate the results, several samples are engraved with optimized parameters. The results admitted the best condition predicted via method. The effect of each parameter on the depth of engraving and the process time were also analyzed and it was found that the laser power is the most effective parameter. In order to control the material structure and its properties after the process, metallography, hardness, and tensile tests were performed. Although there is a small change in the properties of the original material, the results satisfied standard's requirements. Consequently, the absence of heat-affected zone (HAZ) at the laser engraved region was observed.

Keywords: Laser engraving, API 5L, Gas Pipeline, Pipe Tracking, destructive & nondestructive test.

1. Introduction

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Laser marking is noncontact method and regarding adaptation of engraving mechanism with production line, it could be performing online in pipe mill without any contamination and noise. The main technical specifications of marking are pipe mill name, client project number, raw material tracing code and pipe number in manufacture history system. Based on this procedure these items are abbreviated in 10 characters and engraved in circumferential direction of outside surface of pipe end in fixed location. Economical assessment is considered to reach the best traceability in manufacturing and storage level, in coating process and also in the project site; therefore, undesired or intentional pipe substitution in network installation of gas transmission and distribution pipeline could be checked as main result. Generally speaking, engraving in compare with jet printing is more time consuming process that could be neglected when separate station in manufacturing line by using optimized laser is utilized.

In the other hand unique marking on pipes that could be traced in repeatable and stable method is required and limitation of technical specification of API 5L standard shall be reached. In this point of view several engraving depths were assessed and probable damage mechanisms are evaluated by analyzing fatigue and corrosion under insulation assessments on laser marked pipes with different grades and pipe sizes. According to proposed specification and based on API 5L, manufacturer is responsible for marking and regarding laser marking is time consuming process, location and included items of marking were evaluated for optimized tracking and minimum pipe mill process. Also location of marking station in manufacturing process specification were considered.

The final result of this research is an annex for API 5L standard as a permanent, nondestructive marking method. Several acceptable marking methods same as printing, color codes, stamps, name plates or plaques are compared with this method. The main advantage of laser marking are permanency or perdurability, without destruction , contact and entrance of nearby contaminants, high efficiency due to energy concentration, considering HSE points, variable implementation speed in accordance to production line.

Simulation of laser engraving is also performed in Abaqus/Explicite. For the modeling of material evaporation during the process, element deletion is considered. In this research, by using several subroutines like VUMAT, VUAMP, and VUSDFLD and a Python based program, in addition to defining a non-uniform heat flux in Abaqus/Explicite, elements are deleted as soon as they exceed the boiling temperature. One pulse of laser is simulated through an axisymmetric model to investigate the temperature field in engraved region. The simulation was verified based on a previous job, and then used to predict the temperature field in the current research. The results show that the pulse duration is so small that the temperature reached the ambient temperature shortly after each pulse. Therefore, there is no heat accumulation during the process. The absence of HAZ in the experiments was also concluded based on the simulation results.The most important systems for energy and raw material transmission are gas and oil pipelines. Regarding design condition based on variety sizes, thicknesses and grades in implementation of pipelines several sources of pipe miles are used that involves different product specification levels. In this point of view, traceability and tracking of pipes including production step, packing and deporting pipes to coating workshop and finally implementation site and gas injection for operation have its own importance.

In this research, marking method and its technical specifications are assessed somehow without any destruction and damage on function of pipes, they could be traced even after coating and entering earth for buried pipelines. According to quality assurance system in pipe mill, several destructive and nondestructive tests are involved for quality control of pipes in production step. In evaluation of perdurability of proposed marking method, all these test methods and acceptance criteria based on API 5L standard and technical specification of Iranian Gas Standard (IGS M- PL 001 (2)) are considered and all probable damage mechanisms are thought. In different products several types of marking is used which is depend on product properties ، applicability and durability. In general, marking methods are:

1. **Mechanical**: Dot Peening, Die stamping.
2. **Thermal**: EDM and Laser Marking.
3. **Chemical**: Electro chemical Engraving.
4. **Tag** and **Printing** process.

In compare with these methods laser marking has advantages for engraving as a marking method for pipe traceability that mentioned below:

1- Noncontact method
2- Ability to concentration high amount of energy
3- Restricted heat affected zone
4- High quality for designed marks
5- Permanency of marks
6- Without any pollution or bother some contamination
7- Flexibility and accommodation with production line

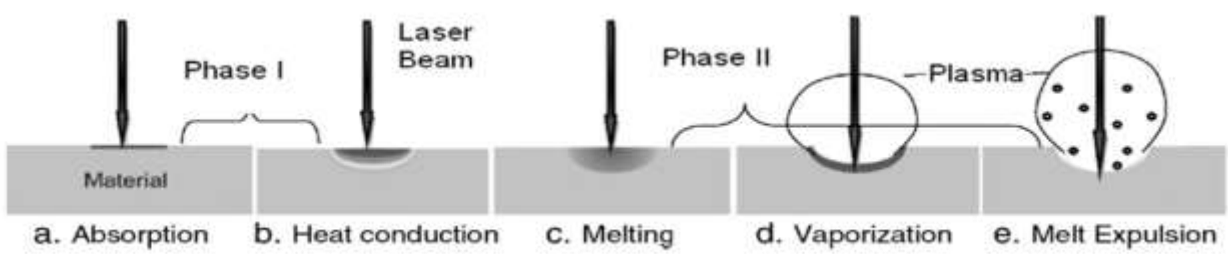


Figure 1. Laser stages.

Mechanical and chemical types of marking for pipes are not acceptable due to destructive characteristics and incompatibility with standard specifications and laser marking is assessed in this point of view. Advantages of laser marking involves noncontact method, focusing energy in restricted area and less heat affected zone, accuracy and durability of marking sketch، without any adjacent contaminants and adaptation with production line. Several types of marks and tags are applicable in gas pipe production line and lase stages are shown in figure 1.

Based on laser mechanism there are several type of laser marking methods. In direct laser Engraving method required shape will be formed on surface by emitting laser directly on base material and vaporizing its surface thickness. Although this mechanism is simple and fast, the first undesired influence is strength reduction. The proposed idea in this research try to delete inevitable strength reduction.

The second mechanism is coating a layer on outside surface and then perform laser emission. In this mechanism strength reduction will be omitted but the excess cost and time for operation are imposed. In other mechanism we could use color as a coating material. Due to nature of sand or shot blasting and pigging process in transmission and distribution pipe lines this mechanism is not useful for gas pipes. These laser mechanisms are shown below in figure 2.

2. Laser marking parameters

The other method in which laser is used called LENS or LISI. In laser Induced Surface Improvement (LISI) or laser- engineered net shaping a powder cover the referred surface and then laser will be emitted to that based on given pattern. The powder grains will be melted and stick to surface. Although this marks are resistive in corrosive and erosive environment, process is time consuming and curve surface of pipe is the main problem for fixing the powder. After assessment all restriction and advantages of methods, laser engraving was selected for marking of API 5L pipes by considering IGS M-PL 001(2) standard specification.

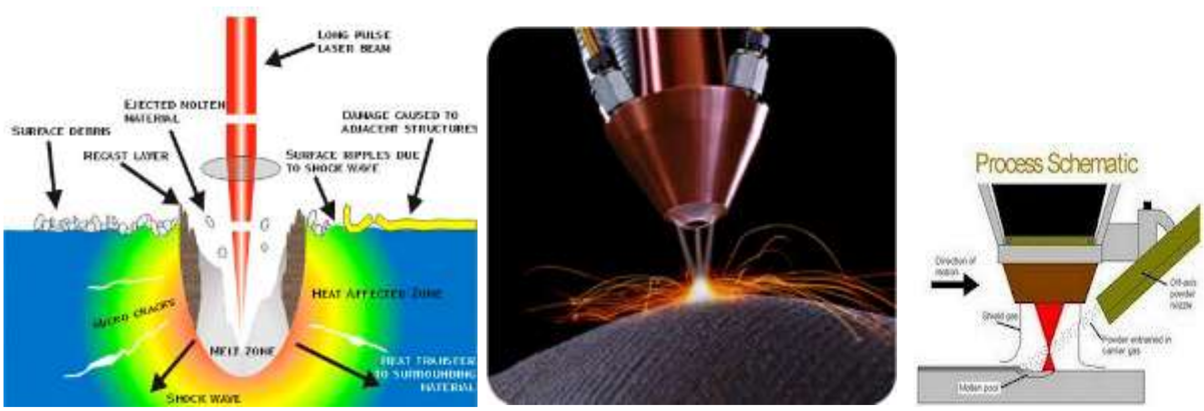
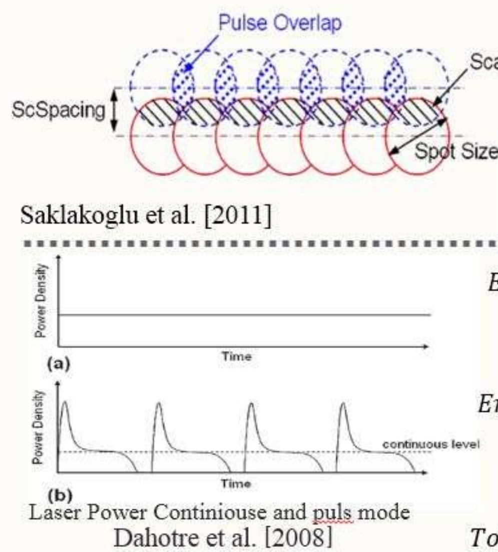


Figure 2. Laser engraving, cladding and coating.

2.1. Laser Engraving

Laser engraving is a method to remove material by use of produced heating due to laser radiation on material surface. The word LASER is the abbreviation of Light Amplification of Stimulated Emission of Radiation. Technical specification of laser and its properties same as cohesion ، mono chrome and radiance focalization ability and its adaption method in computerized system make this method practical and efficient for line of pipe production and marking in manufacture. Laser characteristics are interplay of electromagnetic wave and atoms. Basic principle of laser is based on tree processes; spontaneous dispatch, absorption and induced dispatch. In the first process, photon radiation is due to return of impulse electron to the lower energy level. Reverse process will be happening in absorption Induced dispatch is outcome of inductor photon and up level electron.



$$pulse\ overlap = \left(1 - \frac{v}{fd}\right) \times 100$$

$$scan\ overlap = 1 - \frac{l}{d}$$

$$Energy\ density\ per\ layer = \frac{Energy\ per\ layer}{Length \times Width} = \frac{Power}{Speed \times S_t}$$

- Velocity : v (mm/s)
- Frequency : f (kHz)
- Line distance : l (mμ)
- Laser beam diameter : d (mμ)

$$Energy\ per\ pulse = \frac{Power}{Frequency \times 1000}$$

$$Peak\ Power = \frac{Energy\ per\ pulse}{t_{on\ time}}$$

$$Energy\ Per\ Layer = Power \times Time\ per\ Sn$$

$$Time\ per\ Sn = \frac{Length \times Width}{Speed \times St}$$

$$Total\ time\ of\ scan = \frac{Length \times Width \times S_n}{Speed \times S_t}$$

S 2	S 1	Parameters
27	18	Power (W)
600	400	Velocity(mm/s)
0.030	0.020	Line (mm) Distance
60	40	Scan quantity
30	20	Frequency(kHz)

Figure 3. Basic equations of laser function

3. Destructive and nondestructive tests

The results admitted the best condition predicted via method. The effect of each parameter on the depth of engraving and the process time were also analyzed and it was found that the laser power is the most effective parameter. In order to control the material structure and its properties after the process, metallography, hardness and tensile tests were performed and the results satisfied standard’s requirements. Consequently, the absence of heat-affected zone (HAZ) at the laser engraved region was observed. In this point of view several engraving depths were assessed and probable damage mechanisms are evaluated by analyzing fatigue and corrosion under insulation assessments on laser marked pipes with different grades and pipe sizes. According IGS M-PL 001(2) that is proposed specification and based on API 5L, manufacturer is responsible for marking and regarding laser marking is time consuming process, location and included items of marking were evaluated for optimized tracking and minimum pipe mill process. Also location of marking station in manufacturing process specification were considered. The results of laboratory tests are shown in figure 6. In this step, final technical specifications where written as a procedure of laser marking.

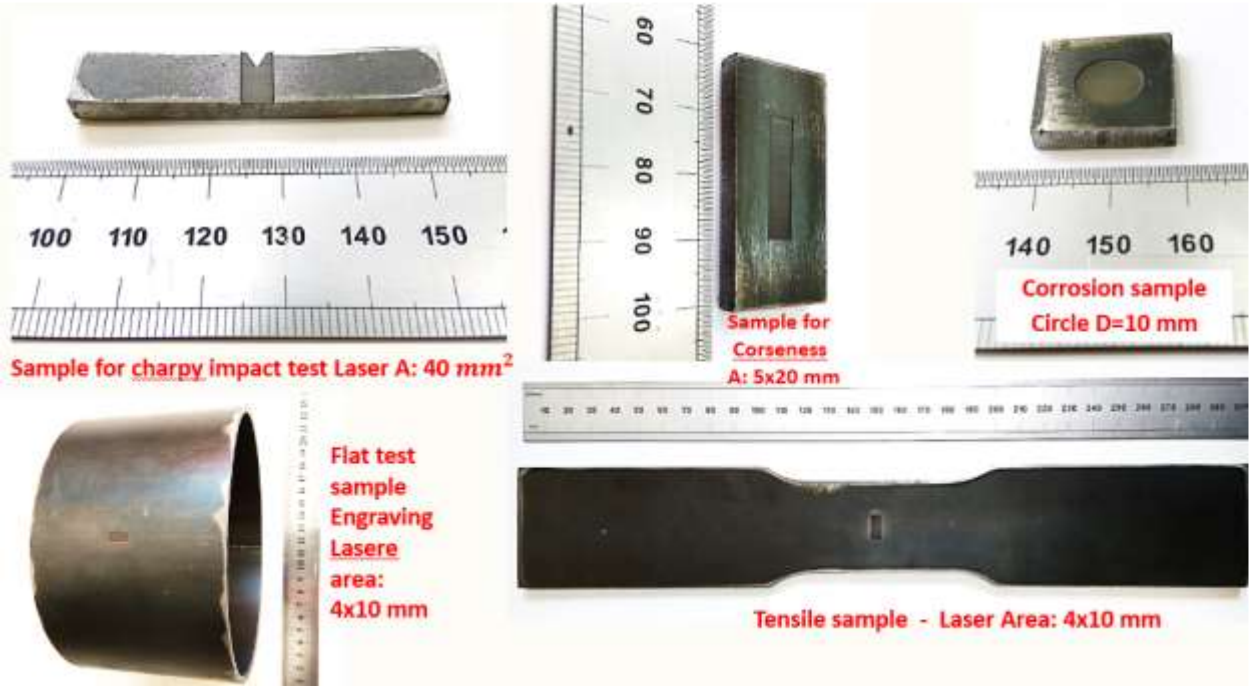


Figure 4. Destructive test samples.

4. Finite element simulation

The results of laser marking is simulated in ABAQUS/CAE Explicit. In this model pipe sample has 4.4 mm thicknesses, and .200 mm depth for engraving. Mechanical properties regarding young's module, Poisson's ratio and density of base metal were selected base on API 5L grade for 6" pipe diameter. Figure 7 shows the meshing structure. After calculating the rate of heat transfer on the holes was evaluated, these conditions simulated by temperature contour that are based on equation 2.

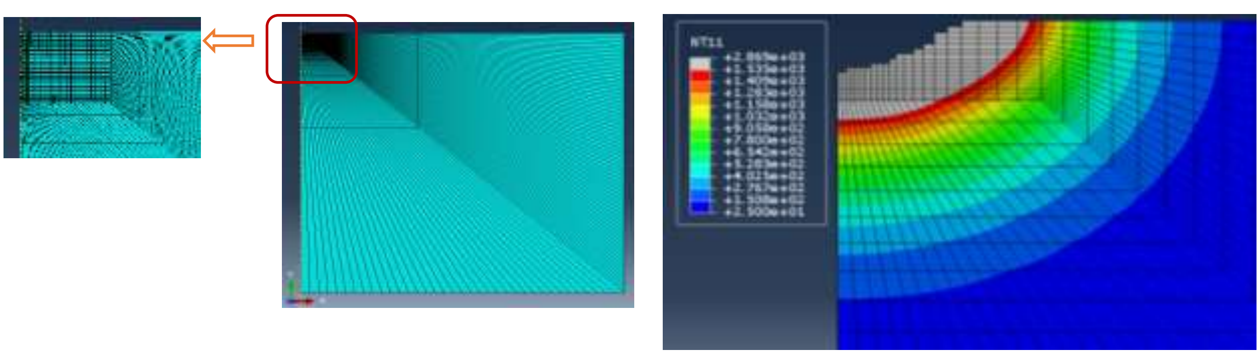


Figure 5. Mesh structure.

For the modeling of material evaporation during the process, element deletion is considered and by using several subroutines like VUMAT, VUAMP, and VUSDFLD and a Python based program, in addition to defining a non-uniform heat flux in Abaqus/Explicite, elements are deleted as soon as they exceed the boiling temperature. One pulse of laser is simulated through an axisymmetric model to investigate the temperature field in engraved region. The simulation was verified based on a previous job, and then used to predict the temperature field in the current research. The results show that the pulse duration is so small that the temperature reached the ambient temperature shortly after each pulse. Therefore, there is no heat accumulation and HAZ[2] during the process. The absence of HAZ in the experiments was also concluded based on the simulation results. These materials simulation could be repeated for other material grades that is investigated for X42 and X52.

5. Conclusion

New method base on laser mechanism has been developed for gas pipes traceability. The method is highly functional, economical efficient, and reliable during pipe production and after implementation. The proposed method was mounted in one pipe mill according to specific procedure in automated mechanism; moreover, regarding nondestructive characteristics and perdurability of marks, laser marking help the supervisory system to control and prevent the cost of undesirable pipe substitution. Finite element simulation by use of Abaqus software confirm the results of research for practical condition. The final sight of project to reach pipe traceability by laser marking is stablish implementation procedure that emphasis on destructive and nondestructive characteristics of laser marking. In this point of view these steps in pipe mill as shown in figure 6 were assessed:

1- Reach adequate depth for laser engraving of gas pipes according to API 5L standard (ISO 3183).
2- Simulation of laser marking by finite element method.
3- Assessed of required depth effects on mechanical and metallurgical properties of base metal.
4- Coarseness and smoothness of surface.
5- Evaluation the permanency and readability of marking.
6- Propose size and font of marking.
7- Preparing addendum draft for standard by focusing on destructive and nondestructive tests.

Figure 6. Pipe mill.

6. Acknowledgements

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