STRIATION MECHANISM IN LASER CUTTING – THE REVIEW

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ABSTRACT
High-power laser cutting is extensively used in many industrial applications.The quality of a laser-made cut is of the utmost importance in laser processing. Any improvements in this area would be of considerable significance, in that it would lead to an elimination of post-machining operations. Although there have been numerous techniques developed over the years, currently there are few appropriate strategies implemented in industry for improving laser cutting quality, partially due to the fact that laser cutting is a highly complex thermal process. The mechanisms governing the laser cutting process are not fully understood. One of the important quality factors of laser cutting is striation (periodical lines) formation on the cut surfaces, which affects the surface roughness and geometry precision of laser cut product. An important weakness of this process is the formation of striations (regular lines down the cut surface), which affect the quality of the surfaces produced.It is the aim to critically investigate and review on the striation mechanism which affect the quality of laser cutting and associated quality improvement techniques. Present trends and future directions are then presented.The elimination of striation formation is of considerable importance, since it could open up a variety of novel high-precision applications.

***Keywords**:* Hydrodynamicinstability, Reintiation, Striation

1. INTRODUCTION
Laser is an acronym for Light Amplification by Stimulated Emission of Radiation. The world's first laser was demonstrated by Maiman using a ruby crystal (Maiman 1960). It is essentially a coherent, convergent, and monochromatic beam of electromagnetic radiation with wavelength ranging from ultraviolet to infrared. Lasers have now found applications in almost every field of engineering, medicine, electronics, etc.

Laser cutting is a common manufacturing process employed to cut many types of materials. Materials which may be cut included ferrous metal, non ferrous metal, stone, plastic, rubber and ceramic. Laser cutting works by directing a high power pulsed laser at a specific location on the material to be cut. The energy beam is absorbed into the surface of the material and the energy of the laser is converted into the heat, which melt or vaporize the material. Additionally gas is focused or blown into the cutting region to expel or blow away the molten melt and vapor from cutting path.

There are several advantage of laser cutting over mechanical cutting, since the cut is performed by the laser beam, there is no physical contact with the material therefore contaminates cannot enter or embed into the material. Laser cutting can produce high quality cut , complex cut ,cut several part simultaneously, produce clean cutting edge which require minimal finishing as well as low edge load during cutting which will reduce distortion

The width of cut or kerfs and quality of cut edges are affected by power of laser, laser beam pulses and the motion of laser beam and work piece.

Section 2 describes the striation in laser cutting. Section 3 describes the brief literature review. Section 4 describes summary of literature and finally section 5 describes conclusion.

2. STRIATION
Striation,[1] i.e. periodic lines appearing on the cut surface, which affects the surface, appearance and geometry precision of laser cutting.

Laser cutting is characterized by the formation of periodic striations along the cut edge. The presence of striations is undesirable since they may act as stress raisers in addition to the unpredictable geometric changes, necessitating the further finishing operations to achieve the smooth surface. In thin sections, these striations are generally clear and regular from the top of the cut edge to the bottom, whereas in thick sections these striations may be well defined at the top of the cut edge and become more random towards the bottom

Despite extensive research efforts directed to address this phenomenon, the mechanism of striation formation is still not completely understood. Several explanations have been put forward for the formation of periodic striations.

The two possible explanations for the formation of striations have been offered based on the pulsation in the molten layer and the side burning phenomenon. The first explanation for the formation of periodic striations is based on the fluctuations and oscillations of the liquid layer caused by instabilities associated with the dynamic nature of laser cutting. These fluctuations of the liquid layer induce perturbations on the cutting edges due to the movement of the liquid layer with the cutting front. The perturbed liquid layer subsequently solidifies into characteristic striation pattern. However, the most widely accepted mechanism for the striation formation is based on the side-burning effects associated with the laser cutting of mild steel. The schematic of mechanism of striation formation by side burning is shown in Fig 1.

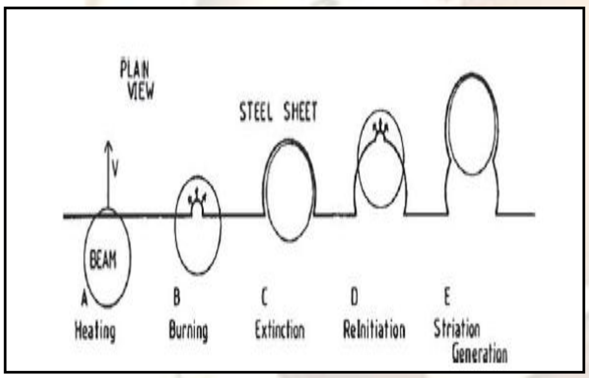

Fig:1 Schematic mechanism of formation of striations during laser cutting

1. Ignition: The focused beam of laser in combination with the coaxial oxygen jet locally heats and subsequently oxidizes the edge of the steel, thus establishing a burning front.

2. Burning: Once the burning is initiated, the burning front receives energy from the oxidation reaction and also from the laser irradiation. This enhanced energy causes the burning front to move faster than the laser beam. This causes the burning front to be ahead of the center of laser beam in cutting direction. The burning front which propagates radially away from the center of the laser beam stops just outside the beam.

3. Extinction: The burning front eventually extinguishes after the laser beam is lagged behind the burning front thus creating a single striation.

4. Reintiation: As the laser beam moves forward in cutting direction, the re-ignition of the cutting front takes place which again goes through a cycle of burning and extinction. The repeated burning cycles as the cutting progresses results in the characteristic striation pattern on the cut edge.

Thus, the cyclic side burning theory suggests that at the cutting speed less than the speed of the reaction front caused by oxidation, sideways burning occur resulting in periodic striations. Excellent analysis of the striation generations by cyclic oxidation reaction of steels have been given based on dynamics of laser-cutting process.

Based on the theoretical and experimental investigation into understanding of striation formation mechanism and characteristic several efforts on elimination striation in laser cutting were attempted over last few years but yet nobody completely understood the mechanism of striation and could not eliminate it completely

3. LITERATURE SURVEY

Kai Chen and **Y. Lawrence Yao** [2] discussed the mechanism of melt ejection and striation formation. Striation formation is depended on the oscillatory characteristics of thin melt film on the cutting front during melt ejection. Cutting speed determine that liquid film will rapture or generate waves on cutting front. They molded a theoretical model based on instability theory of thin liquid film in a high velocity gas jet and the diffusion controlled oxidation theory. From that they conclude that striation is due to the unstable characteristics of the melt ejection combined with the oxidation oscillation. A cyclic pattern is formed on the cut edge by film rapture results in a sudden increase of the melt removal and thus higher oxidation and melting.

Kai Chen, Y. Lawrence Yao and **Vijay Modi** [3] has studied Gas jet has a dynamic effect on the laser cutting quality. Laser cutting efficiency and cut quality are strongly affected by gas pressure and nozzle standoff jet impinging on a work piece. The two improvement forces exerted by the gas jet for melt ejection namely shear force and pressure gradient show the same trend as that of mass flow rate with varying gas pressure and standoff distance. Laser cutting of mild steel under the corresponding condition was performed and the cut quality characterized and recast layer thickness was analyzed by them. They found that removal capability of gas jet in terms of shear stress and pressure gradient is affected by the shock structure of the impinging jet interacting with the work piece. Their experiment produced of cut quality characteristics such as roughness, dross attachment, and recast layer thickness confirms their association with the shock structure and gas removal capability predicted.

N.Rajaram, J.Sheikh-Ahmed and **S.H.Cheraghi** [4]had carried outan experiment on 4130 steel cutting by CO_2 laser with the combined effect of power and feed rate on kerf width, surface roughness, striation frequency, and heat affected zone (HAZ). They found power had major effect on the kerf width, while feed rate played a minor role. At low power levels increasing feed rate leds to a slight decrease in kerf width and slight decrease in HAZ. At higher power level, increasing feed rate to a greater decrease in kerf width a slightly increase in HAZ Feed rate has a major effect on surface roughness and striation frequency. Increasing feed rate generally led to increasing surface roughness and striation frequency. An optimum feed rate for which surface roughness is minimum could be identified.

K. Abdel Ghany and **M. Newishy** [5] evaluate the optimum laser condition for 1.2 mm austenitic stainless steel by pulsed and CW Nd: YAG laser and oxygen/nitrogen as assisting gases. Laser cut quality depends on the laser power, pulse frequency, cutting speed and focus position. Comparing with oxygen, nitrogen produced brighter and smoother surface with smaller kerf increasing the frequency and cutting speed decrease the kerf width and the roughness of cut surface, while increasing the power and gas pressure increased the kerf width and roughness. Best cut quality was found at CW mode at speed from 6 to 8 m/min. Then pulse mode at low speed was 1 to 2 m/min.

CihanKaratas, Omer Keles, Ibrahim Uslan and **Yusuf Usta** [6] conducted an experiment of co2 laser cutting of steel sheet and influence of beam waist position relative to the work piece surface and work piece thickness on the striation formation is examined with SEM and Optical Microscopy. They also molded a kerf width by using a lump parameter analysis. During experimental process they found that beam waist position influence significantly the kerf width is obtained when focus setting becomes similar to the nominal focus length of the focusing lens particularly for thin work piece. For thick plate, the kerf width becomes minimum when the beam waist position moves into the work piece. The kerf width experimental details provided with theoretical lump parameter analysis. They can’t found specific pattern for striation expect the striation width and depth increase with increasing work piece thickness. They found due to non uniform flow of molten, thermal stress are induced and local cracking in re solidification material.

Lin LI, M. Sobih and **P.L.Crouse** [7] had done a practical for striation free laser cutting EN43 M S sheet of 2 mm thickness with 1 KW fiber laser. As well as they proposed a theoretical model to predict the critical/intermediate speed for striation free cutting. They conclude that striation free cutting of thin M S plate is possible at critical speed with specific operation condition which similar to that theoretical model they developed. They also observed that striation is reappearing and roughness is increased at the higher speed than critical speed.

L. M. Wee, P.L. Crouse and **L Li**[8] investigated the effects of the interaction time, irradiance and assistance gas pressure on the output striation angle, striation wave length and the distance of clearly defined striation on alumina subtract. They found that striation is most affected by interaction time, with assisting gas pressure having a secondary effect and irradiance playing a minor role. Interaction time has the major effect on the striation angle, while the assist gas pressure has a secondary effect and irradiance plays a minor role. Increasing the interaction time and assist gas pressure generally leads to a vertical cutting front. Interaction time and irradiance are the significant factors in striation wavelength and upper distance values. Decreasing irradiance and cutting speed generally leads to a decrease of striation wavelength and upper distance.

Koji Hirano and **Remy Fabbro** [9] investigate striation generation mechanism in inert gas laser cutting of steel by observation of hydrodynamics of melt layer on the kerf front. Melt flows in the regions of kerf side and kerf front exhibit instability in different velocity ranges. They observed melt dynamics exhibited instability depends upon the cutting velocity. In lowest velocity ranges ($v<2m/min$) the melt flow in the both the central and side region of the kerf front are instable. In intermediate velocity range ($2m/min<v<6m/min$) the central flow becomes stable, while the side region remains unstable. The unstable region becomes more restricted to the side with increase of v, until whole the region becomes stable at $v=6m/min$. The co existence of the stable and unstable flows in the intermediate range was firstly revealed by this study this is practically important in consideration the mechanism of striation generation, which originated from the instability of the side flow. The observed instability can be explained by a combination of thermal instability of melting process and hydro dynamical instabilities due to surface tension.

Yinzhou Yan, Lin Li, KursadSezer, David Whitehead, LingfeiJi, Young Bao, and **Yijan Jiang**[10] evaluate the effect of gas type, gas pressure, nozzle standoff distance, average laser power, cutting speed and pulse repetition rate on striation characteristics on 1 mm thickness alumina sheet with 400W nano second pulsed DPSS nd: yag laser. The power nozzle standoff distance with a low gas pressure guarantees a smooth and stable gas flow within cut kerf, in order to prevent the potential striation formation caused by the melt oscillation and droplets periodical re-deposition. Cutting speed should be carefully chosen which must be matched with the average laser power and pulse and repetition rate to keep a vaporization driven and continuous cut process one problem remaining to be solved is dross formation. This problem is associated with the current laser cutting system and parameter used. Further investigation is necessary to avoid dross formation while achieving striation free cuts.

Cut quality is affected by laser power, cutting speed, assisting gas pressure, nozzle diameter and focuses point position as well as work piece material. **H.A. Eltawani, M. Hagino, K. Y. Benyounis, T. Inoue** and **A.G. Olabi**[11] focused on cut quality upper kerf, lower kerf and ratio between them and roughness. The upper kerf width increase as power, gas pressure and nozzle diameter increase and it decrease as cutting speed and focal position increase. Cutting speed is the main factor affecting the upper kerf Laser power, gas pressure, and focal position have positive effect on lower kerf width, while cutting speed has negative effect. Ratio increase as the laser power, gas pressure and nozzle diameter and it decrease as cutting speed and focal position increases. Roughness value increases as the cutting speed increases and it decreases as the other parameter increases nozzle diameter has no significant effect on roughness.

3. SUMMARY

Striationis one of the major problemsin laser cutting. Despite extensive research efforts directed to address this phenomenon, the mechanism of striation formation is still not completely understood. Several explanations have been put forward for the formation of periodic striation and lots of research works were done to eliminate the striation but no one completely succeed.Striation reduces the quality of the cutting and creates inappropriate geometrical shape. Minimization in striation improves the cut quality and reduces post machining process. Striation is directly proportional to the surface roughness so by decreasing surface roughness can reduce the striation. In thinner material striation can be controlled but with increasing thickness of material,striation can't be controlled or minimized yet.

5. CONCLUSION

Control of striation can be achieved by stable melt flow from cutting front as well as intermediate cutting speed for a smooth cutting edgeby optimization of the various process parameters like laser power, cutting speed and gas pressure which are major conflict the quality of cutting. From the literature review compare to above all mentioned parameter cutting speed is primary parameter for striation. Elimination of Striationcan be achieved with intermediate range of cutting speed, while beside this range striation is observed.Laser power controls the kerf width such as high laser power produces wider kerf width and vice versa. By optimizing gas pressure,it stabilizeshydrodynamic behavior of molten metal which easily expel the molten metal from the cutting front and reduce the striation.

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