Proceedings of the 1st International Conference on
New Forming Technology, ICNFT, Sep. 6-9, 2004

Remark on Laser Bending Mechanisms

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Abstract: Laser bending mechanism is remarked and its essence is the temperature gradient mechanism. The reverse bending and the thickened mechanisms are included in the temperature gradient mechanism because they are only different phenomena based on different thickness of the material. Experimental result shows that there is a kind of un-convention temperature distribution in the limit thickness specimen under laser irradiation. This phenomenon cannot be explained by the classical Fourier Law and is defined as Pan-Fourier effect in order to explain laser bending mechanism further.

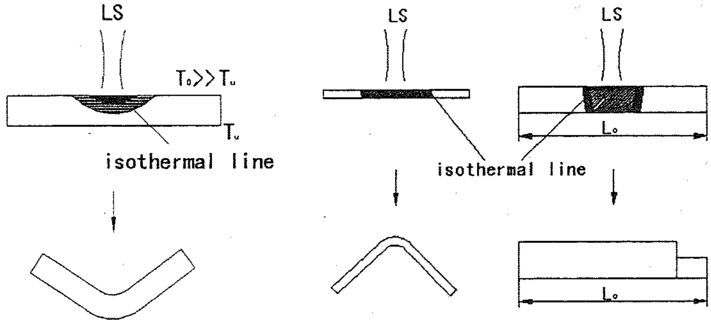
Keywords: Laser bending mechanism, Temperature gradient mechanism, Pan-Fourier effect

1. Introduction

Laser bending is a new flexible forming method and it is presented in recent years. The aim is to secure the thermoplastic deformation of sheet metals without rigid dies through the irradiation of a laser as a heat source. So it can be less limited by manufacture condition. According to optimize the laser technological parameters to control the deformation degree in heated region, the value and direction of sheet metal deformation can be controlled. So it has very wide applied perspective in aviation, mechanical, engineering, industry of national defense and so on. A lot of scholars have done some research work in laser bending mechanism, simulation of laser bending mechanism and laser bending process, influencing factors and changing regularity of laser bending process in the world in order to develop and apply this technique [1-8]. Laser bending mechanism is the foundation of above research work. Only if the laser bending mechanism and its changing regularity of influencing factors are understood clearly, the value and direction of sheet metal deformation will be controlled and this technique will be applied to industry production widely. Some papers, which were published in recent, are related on simulation of laser bending process and analysis of technical parameter and seldom researched on laser bending mechanism. This paper will remark on laser bending mechanism and put forward the new concept based on laser bending mechanism experiment. Finally, laser bending mechanism will be perfected.

2. Research status and analysis

Laser bending technique is begun to research in 1985. Y. Namba researched the material temperature distribution and heated deformation in laser hardening with S45C and put forward new forming method that make sheet metal deform only by heat stress without added external force. The feasibility of laser forming is approved by simply bending experiment [9]. Subsequently, a laser forming research team leaded by Professor M. Geiger and Professor Vollertsen did a lot of research work in laser forming technique. They discovered early that the laser bending mechanism includes temperature gradient mechanism, bending mechanism and thickened mechanism. They are shown in Fig.1 [1].



a) temperature gradient mechanism b) bending mechanism c) thickened mechanism
Fig.1 Laser bending mechanisms [1]

Temperature gradient mechanism is shown in Fig.1.a). When the high-energy laser beam irradiates vertically on sheet metal surface, its temperature rapidly rises. In the same time, the lower surface of sheet metal does not be irradiated by laser beam and its temperature does not change obviously. So there is very deep temperature gradient in the direction of the sheet metal thickness. The material must be expanded with temperature rising so there is un-even compression stress from the cold material around heated region. The sheet metal is easy to deform away from the laser beam because the material yield stress is degressive with the temperature rising. When the laser is shut down, upper surface temperature become lower very quickly, the material shrinks. Due to heat conduction, the temperature of lower surface is up, the material expends. So the temperature gradient will gradually decrease in the direction of the sheet metal thickness. The final deformation direction of the sheet metal is towards the laser beam.

Laser bending mechanism experiment described by published paper [10] shows that for some materials which have obviously phase transformation during the cooling process such as C45, material expands to make the deformation degree away from the laser beam increase. The final deformation direction of the specimen depends on the result of the co-operation of the thermal stress and the phase transformation stress, away from the laser beam or towards the laser beam.

Bending mechanism is that when the sheet metal thickness is thinner and the sheet metal is irradiated by large diameter laser beam, there is smaller temperature gradient in the thickness direction to make the metal sheet deform. In fact, the thinner sheet metal loses stabilization caused by compression stress shown in Fig.1.b). Thickened mechanism is that when the sheet metal thickness is thicker, the sheet metal is irradiated by large diameter laser beam and there is smaller temperature gradient in the thickness direction, some material is accumulated in heating region shown in Fig.1.c).

Analyses show that the essence of laser bending mechanism is the temperature gradient mechanism. The reverse bending and the thickened of the material are only different phenomena based on different thickness of the material. The bending and the thickened mechanisms are included in the temperature gradient mechanism.

In order to research the temperature gradient mechanism, the temperature transfer and distribution inner the sheet metal under laser irradiation must be understood. Known as from some published papers, people think that the temperature disturbance transfers from material surface to inner by simple diffusion. So the relationship between the heat flux density and the temperature gradient is described with the parabola heat transfer model of the classical Fourier law and the temperature distribution is gained with analytic method or numerical simulation so as to formulate technological parameters in laser processing [11-14]. But with developing in application of film technique and nanometer technique, micro-scale heat transfer theory gains more attention. People discovered that when the strong laser pulse irradiates on the surface of micro-scale metal, there is a kind of non-normal phenomenon that inner material temperature is higher than on heated surface temperature. So they think that the temperature turbulence transfers from material surface to inner by heat wave. In consideration of the lag time between the temperature gradient formation and heat transfer velocity, the classical heat transfer model will be modified and hyperbolic heat transfer model is set up. In this condition, non-normal temperature distribution is described through non-Fourier law [15-20]. Obviously the non-Fourier effect must be taken in specific condition that the heating time is shorter than heat relaxation time, the definition region of non-Fourier effect is very limited. According to continuity of heat transfer itself, it is deduced that there is the changing course from the Fourier law to the non-Fourier law. It is verified through the experiment. A kind of non-normal temperature distribution in the limit thickness specimen under laser irradiation is found. Pan-Fourier effect is defined to describe it.

The paper [21] shows that this kind of non-normal temperature distribution in the limit thickness metal under laser irradiation can be calculated by analytical method from the interaction mechanism between photon and phonon and approves that Pan-Fourier effect presented is in existence.

3. Experimental setup and results

The principle scheme of the experimental work is shown in Fig.2 and Fig.3.

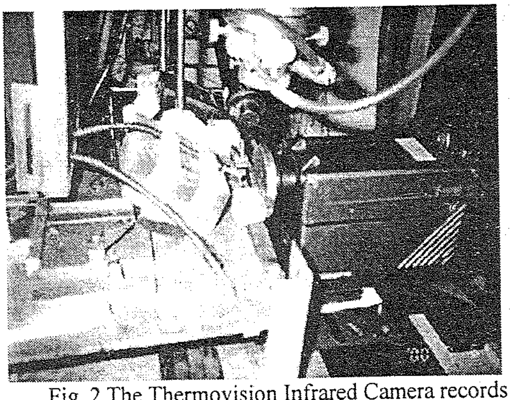


Fig. 2 The Thermovision Infrared Camera records the real-time temperature distribution images

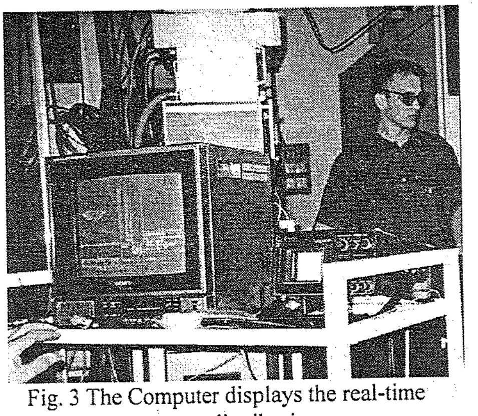
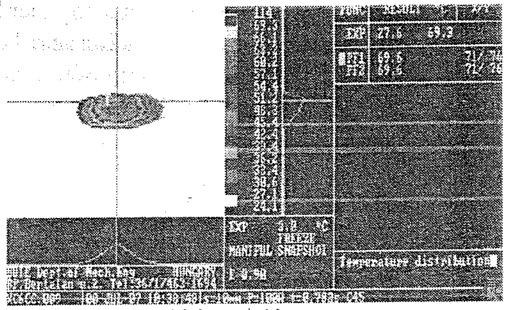


Fig. 3 The Computer displays the real-time temperature distribution

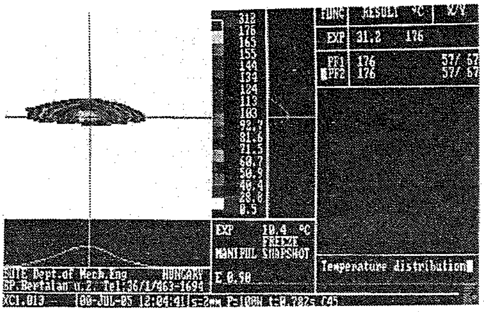
The experiment has been done in the Department of Mechanical Engineering Technology, Faculty of Transportation Engineering, Budapest of Technology and Economics. The type of CO_2 laser and Thermovision Infrared Camera are separately OERLIKON OPL 1800 and THERMOVISION 880 LWB. Laser output power is adjusted to 0~1800W, laser energy distribution obey Gauss distribution, the beam diameter irradiated by laser beam on the specimen surface can be chosen from 0.2mm~11mm. Temperature may be measured from –20℃~1500℃.

The specimen materials and size are chosen as C45 (100mm×2mm, thickness is 2mm, 5mm, 10mm). The specimen is clamped at one end as a cantilever beam and put in the 21mm under focal point of lens (Beam diameter on the specimen surface is 2mm). It is irradiation at the center by the laser beam. Laser output power is 100W. The condition heating time is 0.782s. The specimen surface is sprayed with a graphite coating (Graphite 33) in order to enhance absorption of energy. The Thermovision Infrared Camera records the real-time temperature distribution on lateral area of heated region, and is attached to a computer display. Temperature values are collected by special software so as to gain changing regularity of temperature during laser-material interaction as show in another paper.

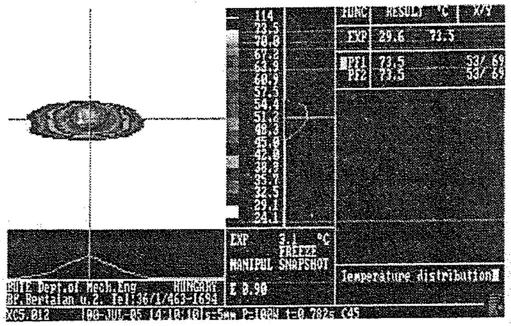
The real-time measuring results of the temperature distribution images at the end of heating time are shown in Fig.4.



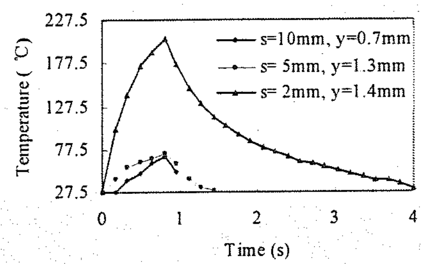
a) Thickness: 10mm



b) Thickness: 2mm



c) Thickness: 5mm



d) Variation of maximum temperature versus time

Fig.4 The temperature distribution images at the end of heating time (t=0.782s)

In Fig.4, different temperature range is displayed by color scale. For the thick specimen as shown in Fig.4.a), the image of the temperature distribution inner material is fit for the result from the Fourier law, the temperature gradually decreased from the surface to inner in the thickness direction. With decreasing the specimen thickness, some non-normal phenomenon that the temperature of inner material is higher than that of the boundary is discovered and the image of the temperature distribution inner material is absolute contrary to the result from the Fourier law, as shown in Fig.4.b); the phenomenon between above two phenomena is shown in Fig.4.c). Fig.4.d) indicates that under same technological parameters the thinner is the specimen, the faster is the heat wave running into limit boundary and heat wave overlap makes the position of the maximum temperature move toward lower side.

Experimental results show that there is a kind of non-normal temperature distribution in the limit thickness specimen under laser irradiation. The maximum temperature is not on the heated surface, but is inner material. The thicker is the material thickness, the nearer to heated surface is the position of the maximum temperature. This is the reason that when the heat wave transfers inner specimen to encounter the thickness boundary, it reflects and is overlapped by incident wave. Under the same technological parameters, the thicker is the material thickness, the slower is the heat wave running into limit boundary, and the less is the strength of heat wave reflection, the less is overlapped effect and the less remarkable is non-normal temperature distribution.

Experimental results indicate that the effect of the limit thickness boundary is almost zero when the material thickness is enough. The image of the temperature distribution inner material is fit for the result from the classical Fourier law, heat transferring to inner material is regarded as simple diffusion. Only when the material thickness is thinner, heat transferring to inner material can be regarded as wave diffusion. Pan-Fourier effect is defined to describe it.

In order to reveal the laser bending essence, Pan-Fourier effect must be perfected in the future such as the effect of the material parameters, the technological parameters and the geography parameters on it, the generated critical condition, heat transfer model, experiment verified and so on.

Research contents will not only impulse the laser sheet bending technique but also provide profoundly theory foundation for research on the others laser processing.

4. Conclusions

Conclusions can be gained from above analysis:

- The essence of laser bending mechanism is the temperature gradient mechanism. The reverse bending and the thickened of the material are only different phenomena based on different thickness of the material. They are included in the temperature gradient mechanism.
- Laser bending mechanism depends on the temperature distribution in the material. Pan-Fourier effect based on experimental result must be perfected so as to reveal the laser bending essence.

Acknowledgements

The authors would like to acknowledge Dr. Antal Sklanitz and Dr. Zoltan Dudas for their assistance during the earlier stages of this work that was supported financially by China Scholarship Council and Hungary Ministry of Education, Natural Science Foundation of China, Aviation Fundamental Science Fund of China.

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