Simulation Analysis of Laser Shock Forming for TA2 Titanium Sheet Based on ABAQUS

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Abstract. The influence of the different laser faculae model and optical field distribution with spatial frequency components on laser shock forming for TA2 titanium sheet metal was done by the binary optical beam shaper and the finite element software ABAQUS, and the dynamic response and forming rule of the deformation of TA2 titanium sheet were analyzed. The results show that after using ring distribution of low frequency light load, sheet metal loading area first produces plastic deformation, occurs the thickness to thin, and with the increase of loading time, plastic deformation area continuously outward expands; under the condition of the same peak pressure and outer diameter of ring laser faculae, the smaller the inner diameter, the greater the deformation and the flatter the bottom; compared with the circular laser faculae, the bottom of the laser shock forming deformation area is relatively flat, the deformation and the residual stress distribution are evener by ring low frequency faculae, which not only increases the performance of sheet metal forming, but also improves the fatigue strength and wear resistance of the specimens.

Introduction

With the increasing development of the laser, its application is more and more widely. As a new kind of sheet metal plastic forming process, laser shock forming(LSF) [1-2] also arises at the historic moment, which has the characteristics such as the fast forming speed, high pressure, high strain rate, without the die/mould and the external force. Therefore, the studies on the interaction between the materials and the laser, deformation mechanism and forming properties have important scientific significance.

Titanium or titanium alloy is applied to the parts in aircraft, satellite and the rocket, and the proportion of the forming curve surface parts is large. However, because of the small batch and complex shape parts, the cost of the forming mould is high by the traditional stamping method, and the forming size is limited by the forming device [3]. As a new type of advanced manufacturing technology with fast, agile and good flexible, laser shock forming is combined with the laser forming, shock processing and plastic forming technology and so on. In order to reduce manufacturing costs and improve efficiency, the laser shock forming technology has application prospect for the precision forming of titanium plate.

The purpose of the paper is to study the influence of the different laser faculae on the properties of forming titanium plate in LSF, to provide theoretical basis for laser shock forming experimental study, to analyze the distribution laws of the stress and strain fields by FEM, to obtain the forming limit of sheet metal under different laser flare shape.

Laser shock forming principle

The strong laser with high power density(GW/cm^3) and short pulse(ns) was utilized to form the corresponding laser light faculae by means of specific binary optical beam shaper[4]. Through the transparent constraint layer(the organic glass), the laser beam exposed to the absorption layer(aluminum foil) covering on the surface of sheet metal.

The absorption layer absorbed energy to vaporize. After vaporization of steam, laser energy was sharply absorbed to produce plasma, result explosion and form momentum pulse, so stress wave spreading to the inside of sheet metal was generated under the effect of constraint layer.

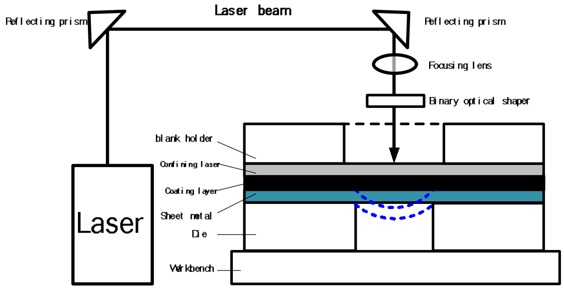


Fig.1 Laser shock forming principle diagram

When the stress wave produced exceeded the dynamic yield strength of the sheet metal, the macroscopic plastic deformation of sheet metal can be occurred. Laser shock forming principle diagram was shown in Fig.1.

Finite element simulation of forming process

The laser shock forming simulation to TA2 sheet metal (Φ 60 mm×0.3 mm) was done by the finite element software ABAQUS. In modeling, the own Johnson-Cook modules in ABAQUS software was selected. Johnson-Cook model equation is shown in (1).

$$\sigma = \left(A + B\varepsilon^{n}\right)\left[1 + C\ln\left(1 + \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)\right]\left(1 - T^{m}\right) \quad (1)$$

Where, σ is the flow stress, ε is the strain, $\dot{\varepsilon}$ is the strain rate. Let the reference strain rate $\dot{\varepsilon}_0 = 1$, then A is the static yield stress; if not consider the effect of temperature(T), then m=0. The other material parameters were shown in table 1.

Table 1 The performance parameters of TA2 titanium plate

Material	A / MPa	B / MPa	n	C	Density ρ/(kg.m^{-3})	Elastic modulus E/ MPa	Poisson's ratio μ
TA2	830	1100	0.15	0.015	4500	107.8×10^3	0.33

In the process experiments, sheet metal was clamped between the blank holder annulus and die. The blank holder was employed to limit freedom of thickness direction, the die restricted the sheet metal forming shape. According to shock wave theory, the forming process induced by laser shock can be ideal into instantaneous load to analyze. The load was directly defined as peak pressure on the plate surface. The topology of the physical model was established as shown in Fig.2.

In order to reduce the calculation time and ensure the accuracy of experimental results, when meshing the elements, the refined grids were reasonable dense in work area, while, the grid dealt with thinning processing in non-working region. Considering LSF process, a certain depth of plastic deformation on the surface of sheet metal was produced, C4R unit was applied, which was an eight-node three-dimensional continuous solid unit with reduced integral model and the hourglass control. The element meshes were shown in Fig.3.

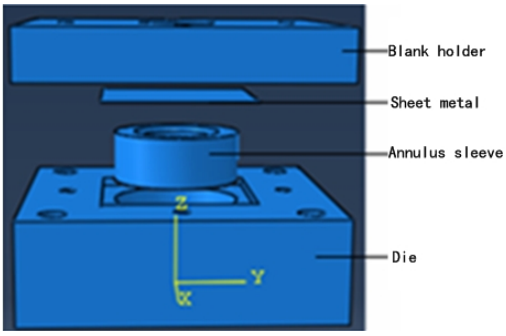


Fig.2 Topology of the physical model

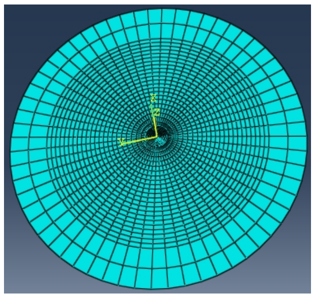
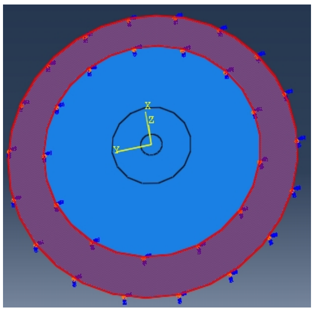
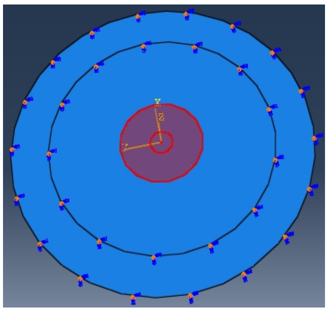


Fig.3 The element meshes

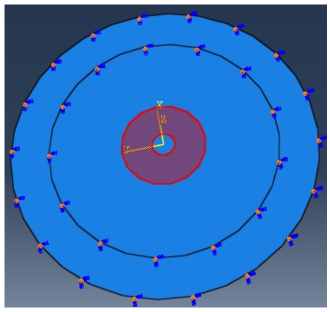
Simulation model was made up of the constraint area, the loading area and the laser faculae loading area, where, the constraint area was a part of titanium plate contacting with the blank holder, the constraint condition was that Z-axis displacement of the sheet metal was zero, in the meantime, the rotation fixed in X- axis and Y-axis. The outside diameter and the inner diameter in the laser faculae loading area was Φ10 mm and Φ4 mm respectively, the boundary conditions were as shown in Fig.4.



(a) The constraint area



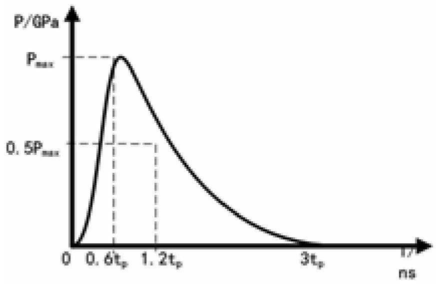
(b) Sheet metal loading area



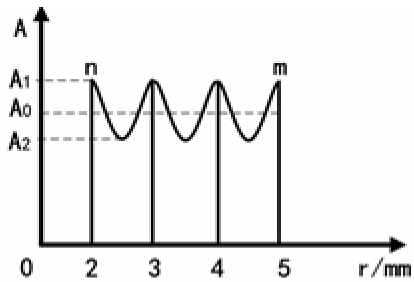
(c) Laser faculae loading area

Fig.4 Schematic boundary conditions and loading area

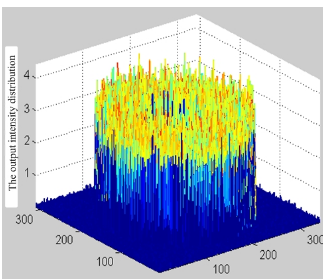
Some researches[5] showed that in the case of constrained layer, the action time(AT) of the shock wave induced by laser can be prolonged about 2~3 times. For example, when the pulse width $\tau = t_p$ ns, $AT = t_p$ ns in simulation. The ring laser faculae were obtained by using the self-made binary optical device. The loading amplitude curve was as shown in Fig.5(a), the spatial distribution of



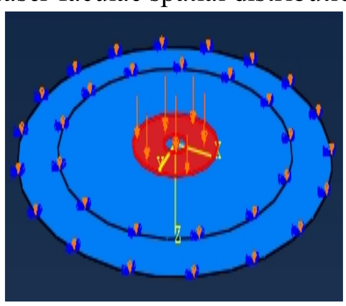
(a) Peak pressure loading amplitude curve



(b) Laser faculae spatial distribution



(c) Three-dimensional laser faculae



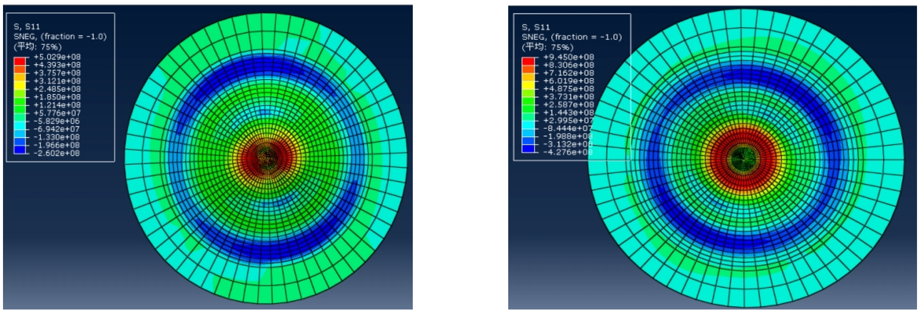
(d) Load model

Fig.5 Definition of load

shock wave induced by the laser in Fig.5(b), The three-dimensional diagram of the ring laser faculae in MATLAB simulation in Fig.5(c), loading model in Fig.5(d).

The results of numerical simulation analysis

The stress field analysis. When interacting between strong laser and sheet metal, sheet metal occurred deformation and dynamic yield with extremely high strain rate in a short time(up to 107 s^{-1}). Fig.6 showed the stress field in different laser intensity distribution. The maximum stress appeared in the laser faculae loading area. The farther distance from the loading area, the smaller the stress. The maximum stress can be achieved 502.9 MPa (Seen from Fig.6a) in loading area of the sheet metal concave by Gaussian distribution. By contrast the maximum stress can be achieved 945.0 MPa (Seen from Fig.6b) by using low frequency ring laser faculae distribution, and stress distribution was more homogeneous. According to the laws of the unloading, the residual stress in the corresponding position was compressive stress (i.e., negative), which will help to improve the fatigue life, hardness, wear resistance and corrosion resistance performance, so the low frequency ring distribution had better effect than Gaussian ring distribution.



(a) Gaussian distribution (b) Low frequency ring distribution

Fig.6 Stress field in different laser intensity distribution

The influence of inner diameter at low frequency ring laser faculae. The influence of ring laser faculae inner diameter on sheet metal forming for TA2 titanium plate was numerically analyzed. The peak pressure of 5 GPa was given. For low frequency ring distribution, the outer diameter of laser faculae was Φ10mm, the inner diameter was selected Φ4 mm, Φ6 mm, and Φ8 mm respectively. Sheet metal forming contour was shown in Fig.7. It can be seen that under the condition of the same peak pressure and laser faculae outer diameter, the smaller the inner diameter, the greater the deformation and the flatter the bottom, which attributed to the larger and more uniform energy.

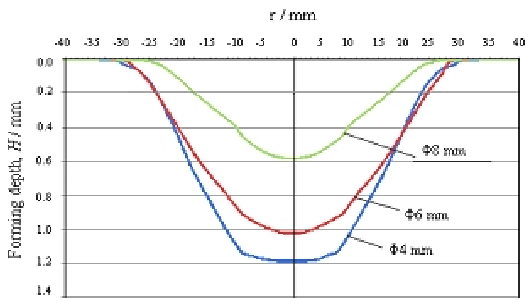


Fig.7 The specimen section in different inner diameter of ring laser faculae

The influence of different form of laser faculae. The influence of the low frequency ring and circular laser faculae on TA2 titanium plate at given the peak pressure of 5 GPa was studied respectively. The specimen section was shown in Fig.8. It showed that ring laser faculae can obtained the flatter bottom of the profile than the circular, however, the forming depth increased by

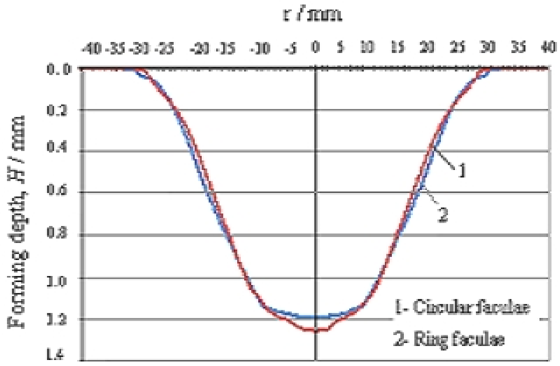


Fig.8 The specimen section in different form of laser faculae

circular laser faculae, which improved the formability of sheet metal.

Conclusions

Sheet metal loading area first produces plastic deformation after loaded by using the low frequency ring laser faculae, which causes to thin the sheet thickness, and with the increase of loading time, the plastic deformation zone expands unceasingly.

Under the condition of the same peak pressure and outer diameter of ring laser faculae, the smaller the inner diameter, the greater the deformation and the flatter the bottom.

Compared with the circular laser faculae, the ring laser faculae can make residual stress distribution evener and the bottom of the deformation zone flatter, which not only improve the forming performance of TA2 titanium plate, but also improve the fatigue strength and wear resistance of the specimens.

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