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TECHNOLOGICAL CAPABILITIES OF FOCUSATORS IN LASER-INDUCED MATERIAL PROCESSING

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Abstract—Experimental results are reported for laser-induced annealing, surface alloying of steel and welding of polymer sheets. The laser beam was shaped by a focusator into an irradiant straight line of constant thickness. An industrial CW CO_2 laser LATUS-31 was operated in either single mode or multimode lasing regimes. Processing with focusator-shaped beams considerably improved the operating characteristics of laser treated details, improved the productivity and cut down the cost of materials.

High-power industrial lasers have been used to advantage in many a material processing application for expensive materials, jigs and fixtures [1]. The cost is low and the workpieces subjected to laser treatment exhibit a considerable improvement of their performance properties. These technological advances rely to a large extent on the reliability of the optical systems redistributing the beam energy over a workpiece with a specified intensity. Elements of planar optics technology offer certain advantages for such applications [2]. We discuss the technological capabilities of such elements, called focusators, in laser-induced annealing and surface alloying of metals and in welding of polymers.

In particular, a copper focusator prepared by electroforming and installed to serve as a redirecting mirror for a power industrial laser will redistribute a Gaussian light beam into a segment of straight line with constant thickness and uniform intensity. In multimode lasing, on the contrary, the intensity and width of the line increase at the midpoint and decrease to the ends.

Table 1 illustrates some of the technological schemes of laser-assisted material processing involving focusators. To form large radii of bending in a hardened workpiece, it is subjected to local annealing with a CW laser beam focused in a straight line and made to move along the specified trajectory. This type of local annealing helps localize the plastic deformation caused by the punch in the annealed zone. Unlike the common bending procedure, this technology does not require straightening of the shelves, and offers a better precision of workmanship as this is controlled by the motion of the light spot. Other advantages include the elimination of die sizing that allows the bending stress to be reduced to 50–30%, use of the universal fixture with the metal consumption for the die being reduced down to one half or one third of the previous amount and smaller allowances for trimming.

For a particular bending operation, the width of the annealing zone may be estimated as

$$a = (0.45 - 0.6)(2r + s)\alpha$$

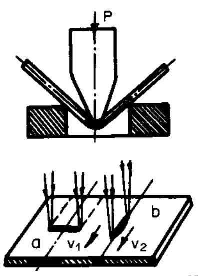
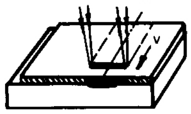
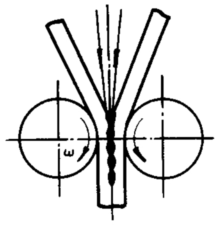
where r is the inner bend radius, s is the sheet thickness and α is the bending angle. The smallest allowable width is controlled by the smallest zone of plastic deformation which does not produce any breakdown of the work. The upper bound of the annealing width is set by the conditions that the bending moment (force) be a minimum, and considerations of accurate workmanship. If the annealing width is increased beyond the upper limit, the required scheme of material flow cannot be realized any longer. This situation results in stronger elastic reaction of the work and in larger inner radii of the bend.

The aforementioned requirements on bending zone annealing can be satisfied by using a focusator that concentrates laser radiation into a straight line with uniform distribution of intensity.

If we decrease the width of annealing zone, then workpieces can be bent to smaller radii (see Table 1 and Fig. 1). The workpiece is annealed by moving the light-line set along the bending edge. A nonuniform distribution of intensity in the light line, in which it is higher at the midpoint and lower at the ends, proved to be favourable for plastic deformations which are not so strong and in turn favour reduced warpage of the workpiece in annealing. For this application, multimode lasing is the most appropriate operating regime.

The light line annealing technology was tested by bending Z-shapes (40 × 50 × 40 × 1000 mm)

Table 1. Material processing with focusator-shaped laser beams

	Operation	Process	Requirements
1	Annealing in bending of sheet material: (a) Large bend radius (b) Small bend radius		Uniform distribution of intensity in the spot. a. The irradiance line is set at right angles to the bend edge. Single mode lasing. Intensity reduces to the ends of the light line. b. The irradiance line is set along the edge of the bend. Multimode lasing.
2	Surface alloying		Uniform distribution of intensity in the spot. The irradiance line is at right angles to the motion.
3	Polymer sheet welding		The intensity reduces toward the ends of the irradiance line set colinearly with the motion. Multimode lasing.

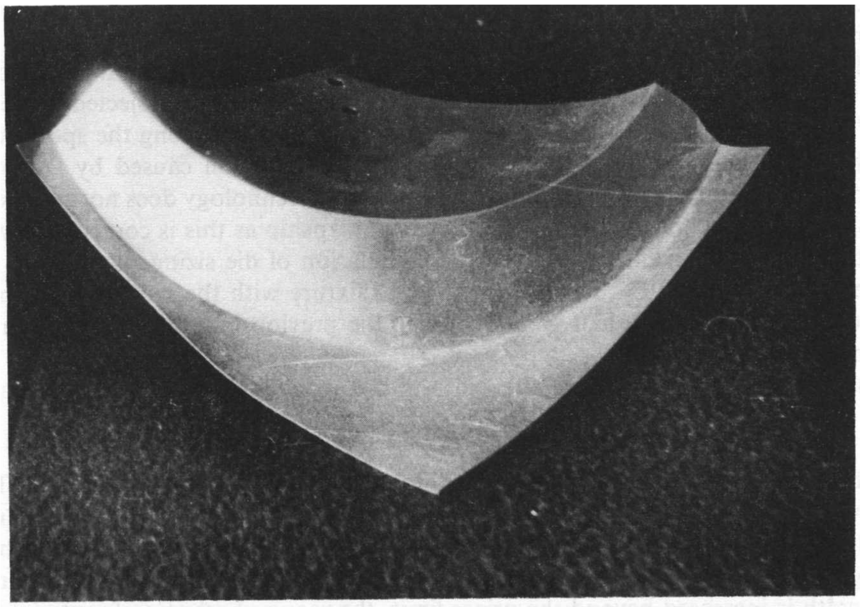


Fig. 1. AMG2N aluminium alloy workpiece produced by bending along a curvilinear contour that was annealed in advance.

of 1.5-mm thick sheets of AMG2N and ADON aluminium alloys. To reduce reflection, the workpieces were coated (in the annealing zone) with water emulsion of soot (40%) and dried at 70°C. The beam of a 0.7 kW CW CO_2-laser of the LATUS-31 type was focused into a 1.0 × 12 mm line spot that was moved at $v_1 = 0.3$ m min^{-1} along the profiles for large bend radii and at $v_2 = 0.7$ m min^{-1} along the profiles for small bend radii. The loss of strength in the annealing zone was $\sigma_a/\sigma_h = 0.4$, where $\sigma_h = 18$ kgf mm^{-2} was the cold working hardness of the material before annealing and σ_a was the yield limit of the metal in the zone of annealing. The bending operations were conducted in a 25-ton crank press making 160 strokes per minute. In contrast to the generally

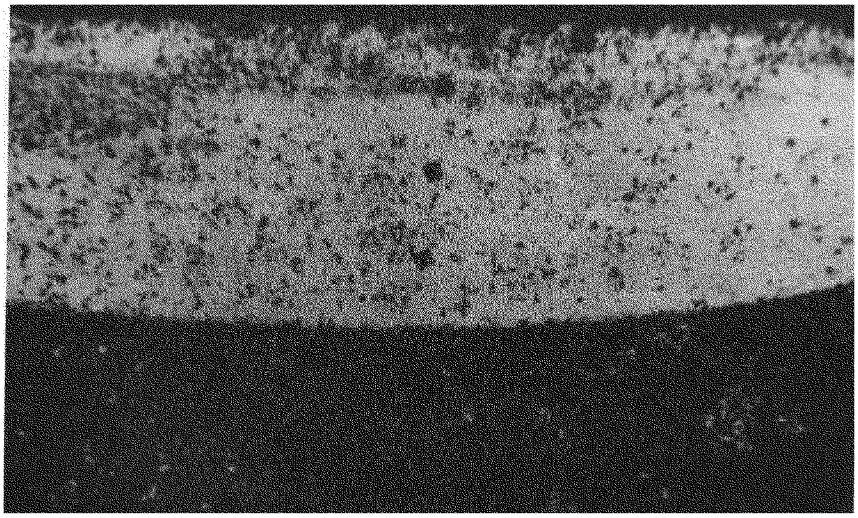


Fig. 2. Microstructure of a layer of U8 steel hardened by laser-induced alloying with WC + Ni.

accepted bending technology, the stamping force was reduced to 0.5–0.4 of the usual effort, and productivity increased two fold. The laser was tuned to the multimode lasing regime by an appropriate choice of gas mix and the parameters of gas discharge.

Another application where focusators may be used to advantage is concerned with the deposition of wear and impact resistant coatings that produce a 2–3 times longer life for expensive details and assemblies. Wear resistant coatings are used on the working surfaces of edges of dies, punches, etc., and on details operating in a high stress and temperature environment. A 180–220 μm deep surface hardening of steel up to 12,000–14,000 MPa is achieved by the plasma deposition of carbides of heat resistant metals, say WC + Ni, followed by a CW laser treatment. A focusator projecting the laser beam uniformly into a straight line (see Table 1) affords processing regimes at temperatures and velocities that prevent the formation of fissures in the coating. Figure 2 shows the microstructure of a steel layer hardened by laser alloying. The depth of laser heat penetration in the system with a focusator is uniform over the whole of the workpiece surface.

In lap welding of polymers by a CW laser, focusators projecting the laser beam into a straight line (see Table 1) can be also used to advantage. The plastic sheets are placed between two pressing rolls and set at an angle of 75–85° to the direction of sheet motion. The laser beam in the form of a light line oriented along the line of contact of the material heats the material locally and produces a melt zone. In order to achieve strong welds, the melting must be deep while the solidification rate of the melt must be sufficiently low. Therefore, the preferable laser operating regime is single mode lasing which provides a higher power density at the midpoint of the light line. The strength of the weld and its sealing is ensured by pressing the sheets between the rotating rolls.

In summary, focusators capable of projecting laser light into a high-power density light line can be used to advantage for local annealing of sheet materials, surface alloying of steels and welding of polymers. Use of these planar optical devices considerably improves the operating characteristics of laser treated details, raises the productivity of material processing, and cuts down the cost of materials.

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