Study on laser welding of stainless steel/copper dissimilar materials

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Abstract. In this paper stainless steel/copper laser welding was investigated by controlling the processing parameters like welding speed and laser power. Welding the dissimilar materials of stainless steel and copper presents a series of problems. Differences in the physical properties of the two metals, including the melting point, thermal conductivity and thermal dilatation are the main reasons for obtaining an inappropriate laser welding bead. Particularly, the laser welding process of copper is complex because of the very high reflectivity of cooper and in almost situations it requires a specific surface pre-treatment. The main objective of the study conducted in this work was to laser weld a structure used in pressure measuring and control equipments. In order to satisfy the conditions imposed by the sensor manufacturer, the difficulty of obtaining flawless joints was represented by the very small dimensions of the parts to be welded especially of the elastic spiral thickness made of steel.

1. Introduction

The characteristics of laser processing technologies such as flexibility, the ability of manufacturing miniaturized components, repetitiveness and consistency of results, the ability to process very hard materials, facile automation offers major advantages compared with conventional processing technologies [1]. In laser welding process, the mechanical and thermal constraints imposed by the materials are minimal, thus obtaining a high quality weld seam in high productivity conditions. Welding of dissimilar metals or alloys is important in order to gain flexibility, but often appear problems due to inter-metallic reactions (formation of brittle phases and the segregations of high or low melting point phases), so affecting the performance of the weld bead [2]. Another important aspect in welding two metals or alloys is the differences between the melting temperatures or thermal conductivities of the materials [3]. During laser welding of dissimilar metals, even it is a high difference between the melting temperatures of materials, the using of high power density permits an instantaneous melting of both metals [4].

In dissimilar laser welding, a general rule is that the mechanical and corrosion resistance of the joint has to be at least comparable to that of the metal characterized by the lower properties [2]. In order to satisfy this condition, it is important to reduce the presence of inter-metallic phases. In laser welding between cooper and stainless steel a major problem is the appearance of hot cracking in heat affected zone of the steel, cracks induced by the diffusion of the copper into the grain boundaries of the unmelted steel. In dissimilar laser welding, the high differences between melting points of materials do not influence the melting depth in the two materials, due to the high temperature gradient induced by the light spot, thus obtaining a symmetric weld bead.
In mechatronics field, the connection of different materials is important due to the complex structure developed [5], [6].

![Figure 1. Induction welding equipment.](image1)

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In order to evaluate the integration potential of laser welding in a fabrication line of a pressure sensor, joining cooper with steel was evaluated in this paper. The old solution for joining the steel-cooper structure was induction welding equipment with a low rate of automatization.

2. Presentation of the genuine solution

There are a lot of applications covering a wide range of technical fields, due to the advantages of laser welding – the possibility of welding materials with various properties, with complex shapes and dimensions, achieving a high welding speed, a great quality of laser bead, the entire automatization of the process. For instance, excepting the known industrial application such as energetic equipments, chemistry, planes, there are some recent applications in medicine, electronics and appliances industry.

A special application of laser welding is the laser Nd: YAG where some bearings made of safire and rubine are grounded on iron base and they are used in some measuring devices [7]. The advantages of these bearings are a high accuracy level, low dimensions and weight, frictionless, so they could run without lubrication and a good level of thermic stability. This precious stones have low friction coefficient about 0.1 – 0.15. The safire has a hard level of its mechanical crack characteristic, it is 9 on the Mohs scale and it is very stable during some work period. Until now the laser welding is the only process which could influence very low its thermal properties (figure 2).

![Figure 2. The laser welding for grounding the safire pieces.](image2)

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Some others applications of laser welding are the safire valves used in hydraulics or for pressure systems working with abrasive liquid, the food industry and medicine industry.
Figure 3. Some applications for safire and rubine used as valve support, air pressure flow, ink valve.

Another direction of laser welding applications is founded in energy industry for manufacturing some sensors and micro-sensors, a technical field where our team has a great experience with some experimental researches and some scientific publications.

Figure 4. The radioactive capsule made of stainless steel welding by using laser ray.
Figure 5. Some examples of using the Nd: YAG laser for electronic industry (electronics components) and pace–maker device.

The FEM analysis by using the soft-ware ANSYS 12, CATIA V5 and SolidWORKS affords the tension and displacement computations for the laser welded parts and finally they point out the wicked sections and the possible cracks sections [8]. Meantime the three – dimensional model and the simulation could be made. Consequently, we may choose the optimum values for weldment parameters, in order to avoid the crack and unpleasant phenomena. These values of optimum parameters should be linked with the welding material as well as with the type of weldment we use for. After the welding process is done, we have to test the quality of the bead using the known contact or contactless methods.

The technological working parameters, such as impulse energy [J], the step time [ms], the working power [W] and the maximum impulse power [kW] will be optimized and adjusted for the materials we have to use.

3. Experimental setup

The parameters of the laser radiation, adjusted upon the characteristics of the welding materials and the disposal of the welded parts must ensure the raise of the $T_{ms}$ temperature from the joint area to a value which is superior to the melting temperature – $T_{melting}$, the vaporization temperature $T_{vaporization}$ as following:

$$T_{melting} < T_{ms} < T_{vaporization} \quad (1)$$

The laser action time frame or the displacement speed of the parts/beam is chosen, so that the penetration of the melting frontline in the materials takes place before the evaporation of their superficial layer, basically the maximum melting depth being reached when the temperature of the material from the surface reaches the boiling point.

The rapid heat conduction in the two materials from the joint area depends on the thermic diffusion – d of the materials and the type of contact between the parts that are being welded [9].

Taking into account the conditions, the expression of the temperature field in the welded materials[9], according to the flux intensity absorbed per unit area – $I_0$, the radial distance - r from the laser beam center, the penetration depth of the material – $z$ and the time – $t$, can be determined using the following expression:

$$T_{(r,z,t)} = \frac{I_0 a^2}{k} \sqrt{\frac{d}{\pi}} \int_0^{\infty} \frac{1}{(4\pi)} e^{-r^2} \frac{e^{-r^2}}{(4\pi t \sigma)}$$

where: $\tau_t$ time length of the laser pulse.

By imposing certain conditions, the thermal time constant CtT can be defined as the timeframe in which the temperature of the profound mass of the melt has the same order of magnitude as the temperature of the laser irradiated surface. When the laser action timeframe is much lower (the displacement speed is too high) than the thermal time constant CtT of the material, an homogenous
melt of the materials around the weld seam will not be obtained, having unfavourable consequences over the quality of the welded assemblies[10].

Figure 6. The experimental setup for the grounded device for aligning the parts with laser welding by using the rapid prototyping.

Figure 7. The SWP 6002 welding system – (a); the panel for laser numeric control – (b); the welded parts – (c); image of the parts that will be welded (acquired from the stereomicroscope), 10X zoom – (d).
Due to the small dimension values of the parts that would be assembled by laser weldment requiring aligned conditions, it was designed and manufactured a device for limiting the degrees of freedom and positioning the part. The main demanding was the best quality and optimization of welding bead (figure 7).

The device was manufactured by using the 3D printing with fused deposition modelling that has the following advantages: the part could be manufactured during a very short period; there is not pollution danger; there are not liquid polymers; the materials could be change rapidly; there is not material loosing during or after the manufacturing; the system is not a very complex one and may be used for laboratory experiments shortening the time spent between design stage and final results.

4. Images involving the laser bead defects
In order to visualize the laser bead, we have used a value of zoom 20X – 1280X for a microscope that has the head with rotational movement with three objectives and two eyes - pieces working with 5X and 16 X respectively, USB port and adaptive software (figure 8).

![Figure 8](image)

**Figure 8** The inspection of laser weldment.

(a) ![image](image)

(b) ![image](image)

(c) ![image](image)

**Figure 9.** a, b – Defects at the beginning of the weldment due to the mistaken about working parameters; c – weldment correctly done.
As we may infer from figure 9, a, it is represented the mismatch due to uncompleted weldment because of mistaken about choosing the process parameters. Figure 9, b shows another type of defect due to the fast contact between the laser ray and parts at the beginning of weldment process as well as its ending. Finally, figure 9, c is about an accurate weldment.

We may observe the melt at the beginning of the weldment involving the destroying of part surfaces. The working parameters for both working conditions are given in table 1.

| Laser working parameters | The first probe  | The second probe | The third probe |
|--------------------------|------------------|------------------|-----------------|
| SWP 6002 (Nd: YAG)       | Fig 9, a         | Fig 9, b         | Fig. 9, c       |
| Electrical tension (V)   | 225              | 231              | 233             |
| Impuls time (ms)         | 1.8              | 1.9              | 1.9             |
| Impuls frequency (Hz)    | 1.9              | 2.0              | 2               |
| Focus : (Ø)              | Ø 10             | Ø 10             | Ø 10            |

This type of defect could be avoided by using the dead weldment bead of “dead pieces” at the beginning and at the end of the process, affording the suitable choosing of parameters apart from the welded parts.

5. Conclusions
From the examples presented above we learn that the Nd :YAG laser is used for very small dimensions of the material (under 1 mm). The emission way provides a well control of energy quantity used for working, so the unpleasant effects such as deformations and thermic effects are avoided.

The main advantages of laser using in manufacturing are: the manufacturing of whatever material or dielectric, without considering the piece strength, but the material surface should have enough power needed for laser ray absorption; shortening the manufacturing time, because the process is done instantaneously; the missing of deformation that could appear inside the part after the manufacturing, because it is not a mechanic contact between the part and device; parts with small dimensions or having complex shapes could be manufactured; it does not require controlled working atmosphere and special safety conditions; the parts placed in transparent environment could be manufactured; the manufacturing allows the complete automation and numerical command; it could be realised simultaneously some processes by using the same laser system device; it could provide very accurate positioning of the parts in front of laser ray, so higher accuracy manufacturing could be reached.

Although the presented principle has a lot of advantages, there are some disadvantages we have to take into account. One of the most important is the preparation of the parts before the manufacturing. They have to be very clean and without other pollutants. The welding energy vaporises these elements, so some defects could appear as cracks for instance. There are materials, cooper and aluminium, that should be cleaned before starting the process.

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