Contribution to laser material processing

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Laser beam, material processing, laser welding, laser marking, laser micro-alloying, thin films deposition, process control, laser-arc hybrid welding process, Pulsed LASER-(micro)TIG.

1. Introduction

Nowadays, the use of laser beam for material processing is less an “exotic” application but it became more and more an industrial requirement when one thinks about productivity and efficiency, automation and repeatability. This is sustained both by the current developments related to laser equipments, which became more and more affordable [1], but also due to the sustained RTD related to optimization of the laser material processing technologies and to the development of new and innovative applications.

One should also mention that the laser material processing market was affected by the recent economic crisis showing the biggest decrease in its history (aprox. 30% 2009 compared to 2008), mainly due to the cut in demand for sheet-metal-cutting high power lasers [2].

The main industrial applications of lasers for material processing are related to: cutting, welding, soldering and brazing, surface modification (e.g. hardening, cladding, glazing and wetting modifications), scribing, sheet metal bending, marking, engraving and structuring paint stripping, powder sintering, synthesis, brazing and machining [3] [4].

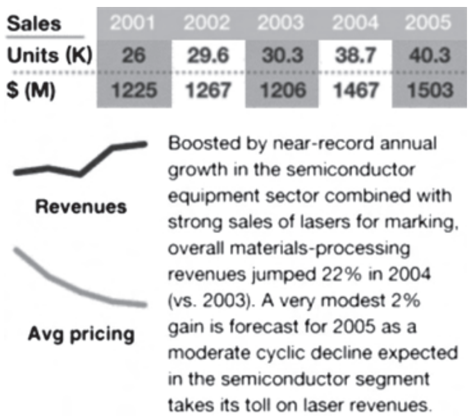


Figure 1. Material processing laser market share [1].

The wide area of industrial application of laser material processing, in terms of technology and materials, is also related to the with well-known general advantages of laser beam materials processing: a non-contact, non-contaminant process, highly flexible, easy to control and automate.

At the same, the developing of new applications related to laser material processing in respect to the newly developed advanced materials [5] [6] and related applications [7] represents one of the scientific priorities at the international level in respect to improving the fabrication processes by applying innovative technologies and re-structuring the traditional industrial sectors.

Following this international industrial demand, since 1998, laser material processing is one of the RTD priorities of ISIM Timişoara, and this paper presents some of ISIM’s contribution to the laser material processing field.

2. Contributions to laser material processing

Beside the “classical” applications, i.e. cutting and welding, which are focused on micro-processing and processing of newly developed materials (e.g. nano-structured / micro-structured metal matrix composites, micro-welding of memory shape alloys, laser beam welding of plastic materials), other applications are studied as well: marking and engraving, thin film coatings deposition by using pulsed laser deposition (PLD), developing of multi-functional micro-layers using laser beam micro-alloying and direct laser powder deposition.

Beside laser beam processing applications, another important RTDI direction in laser beam material processing is the development of new processes, i.e. the laser – arc hybrid process and to expand its usability to the new materials.

The contributions to the laser beam material processing that were obtained at ISIM Timișoara, can be structured in:

– *pulsed laser welding*

• development of pulsed laser welding technologies for specific applications (similar and dissimilar materials)

• development of pulsed laser welding technologies applied in dental technology (repair welding, repair build-up / form shaping, dissimilar materials joining)

• pulsed laser welding applied to metal matrix composites (MMC)

• pulsed laser welding as a more efficient alternative to classical joining methods

• pulsed laser welding of thermo-plastic materials

– *pulsed laser micro-structuring*

• pulsed laser micro-alloying of thermal sprayed layers (metallic and ceramic materials)

• thin films deposition by PLD (metallic and ceramic materials)

• laser marking of MMC’s

– *process control*

• development of integrated system and components for evaluation of weldability of thermoplastic polymers and real-time monitoring and process control

• applying of IR thermography for characterization of Pulsed LASER-(micro)TIG hybrid welding

– *process development*

• Pulsed LASER-(micro)TIG hybrid welding process development (devices, process characterization, process optimization and development of joining technologies)

• design and realization of devices for laser powder deposition

– *other types of contributions*

• fume emissions evaluation of pulsed laser processing of nanostructured MMC’s.

Sudarea şi Încercarea Materialelor

2.1. Pulsed laser welding

A differently designed and more efficient (energy conversation wise) type of cathode for an ion generator oven made of Ta required the development of a specific joining technologies, Figure 2 [8].

Based on the joint characteristics and requirement of the joined components (low electrical resistance and low deformation to avoid the damage when functioning at high temperatures) two unconventional welding processes were used: electron beam welding for the banded electrodes – flange joints (40x2x2mm) and manual laser beam spot welding for tube – flange joints (0.3x0.3mm). The main challenge of applying the pulsed laser welding process application was to ensure a minimal thermal deformation to minimum which was accomplished through the designing of the special clamping device, by determining of the process parameters that did output a weld that satisfy the electrical conductivity and has minimum linear energy input on the work pieces and to the establishing the proper order of the welds.

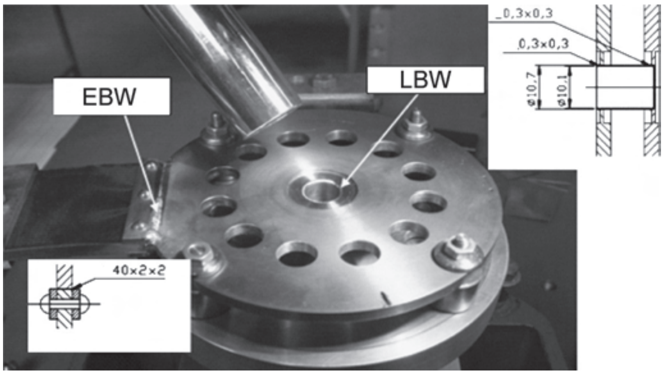


Figure 2. Ta ion generator oven components and the realized joints [8].

One should mention that if for the upper side joint other welding process could have been used (e.g. micro-plasma or micro-TIG), for the bottom one, the limited space would have made the joint very difficult with another process. At t he same time, in order to limit the thermal input, cooling times would have been needed for electric arc based joining processes.

Applying pulsed laser welding for joining of Zn coated thin sheets used in ventilation systems was also studied in respect to the efficiency and to the inherent damage to the Zn coating. The surface and root aspect of such a joint is presented in Figure 3, while the macroscopic structure of the joint in Figure 4.

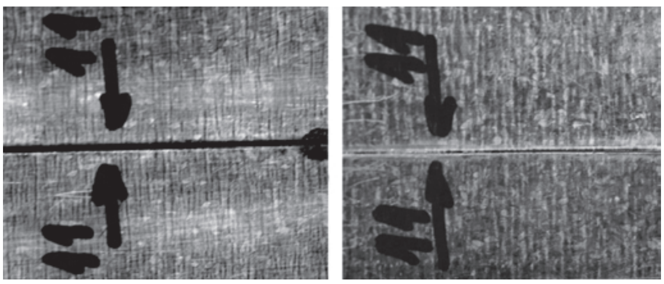


Figure 3. Visual aspect of the weld: top surface joint root (pulsed laser welded Zn coated thin metallic sheets).

With process optimization the following characteristics could be obtained for 0.8mm thick sheets:

- weld width: 0.77mm (surface) and 0.35mm (root)
- width of the affected Zn coating: 2x43μm (joint surface) and 2x35μm (joint root)

Comparatively, the root of a similar joint is presented in Figure 5, realized with another low heat input modern arc process - CMT (Cold Metal Transfer), showing a rather wide area of damaged Zn coating (approximately more than 5 times wider when compared with pulsed laser welding process).

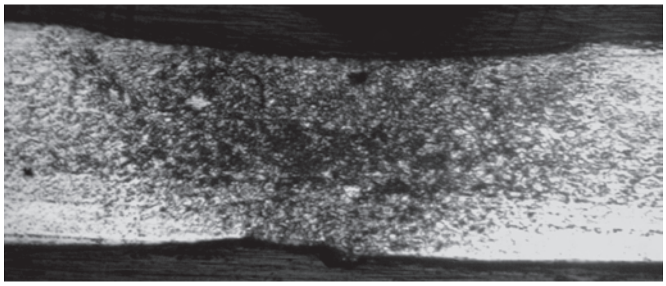


Figure 4. Macroscopic structure [Nital 2%-100X] (pulsed laser welded Zn coated thin metallic sheets).

Figure 5. Root aspect of a CMT bead-on-plate (1.00mm thickness, 1.2mm wire).

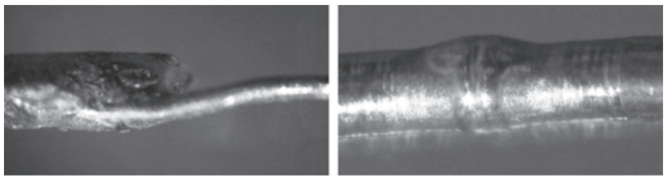


Figure 6. Visual aspect of a soldered contact and pulsed laser welded wire [9].

Pulsed laser welding was also applied to join thin wires for electrical contacts with possible MEMS applications and compared (Figure 6) with other possible joining processes [9]. The experiments revealed the lowest increasing of the electrical resistance and the lowest width of the heat affected zone for the laser welding process, i.e. up to 8-9 mΩ increasing of the resistance and up to half of a millimeter for the width of the HAZ.

Studies [10], [11], [12] were done of pulsed laser welding applied for dentistry applications that involved either welding with and without filler material, build-up welding or near-shape repairing of various prosthesis components. At the same time, the welding of dissimilar materials used in combined dentures technology [13].

Figures 7 and 8 shows two of the most common possible defects encountered in dental prosthesis appliances and their repair by means of pulse material processing, while Figure 9 shows a joint between two dissimilar materials for a heterogenous component.

These studies demonstrated that the pulsed laser beam welding process applicability limitations for repairing removable dental frameworks are related to the beam's lack of access in some defects area (e.g. because of the framework geometry) or when large defects are present, and for the cases the repairing cannot be made directly. The latter ones can be repaired by casting the missing part and welding it to the framework.

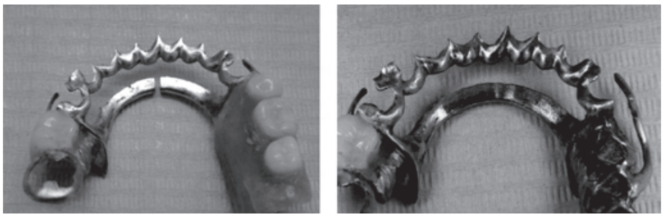


Figure 7. Broken lingual bar repaired by pulsed laser welding with filler material [11].

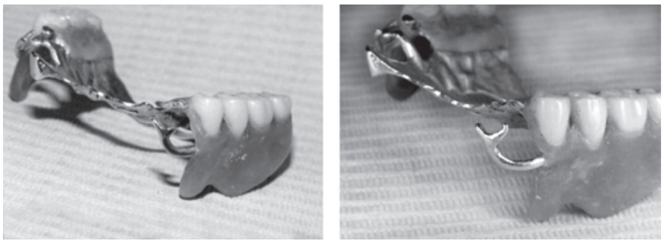


Figure 8. Casting defect at a Roach clasp repaired by laser build-up welding [11].

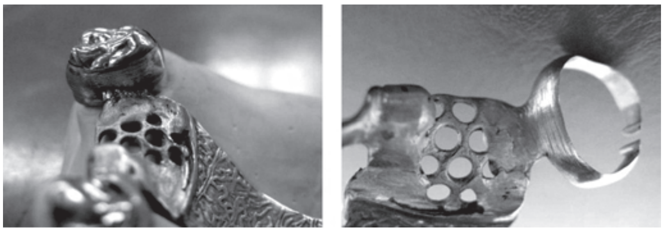
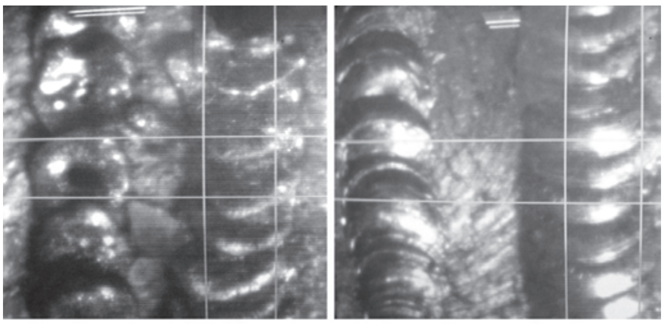


Figure 9. Heterogeneous joint (CoCr – NiCr alloys) between the open ring and the rest of the removable framework [13].



a b

Figure 10. Al – AlSiC MMC processed by pulsed laser: a – unstable processing, b – stable processing.

Following the RTD in the field of nanostructured materials and focused on the realization of nanostructured MMC's, studied were done related to laser beam processing of these types of material, in respect to their weldability (by applying statistical modeling) [14], to the specific fume emissions when processed by laser beam [15], means to reduce their porosity (identified as one of the challenges when processing with laser beam the MMC's) [16], and summarizing the technical and environmental results related to laser processing of low friction nanostructured composites [17].

Figure 10b shows the visual aspect of a Al – AlSiC metal matrix composite processed by laser with a stable weld seam and no important spattering after the optimization of process parameters.

The studies related to laser beam processing of the MMC's revealed some important information:

- the stability of the process is influenced by the porosity and lack of homogeneity specific to these materials
- the stable processing parameters window is quite small and it is strongly influenced by the material's homogeneity
- while after laser beam processing the particle dimension of the generally increase, most of them remain in the nano domain, in order to preserve the material's special characteristics but at the same time, this fact raises concerns regarding the fumes emissions

2.2. Pulsed laser microstructuring

The pulsed laser micro-structuring performed RTD at ISIM Timişoara was focused on laser marking applied to newly developed MMC's, laser micro-alloying of thermal sprayed surfaces and onto thin films deposition by pulsed laser processing.

The laser marking RTD was focused onto determining the influence of the process parameters onto the processing of low friction nanostructured composites (CuAl-SiC, CuSn10-C, W-Cu-Ni) and the marking results [18], Figure 11.

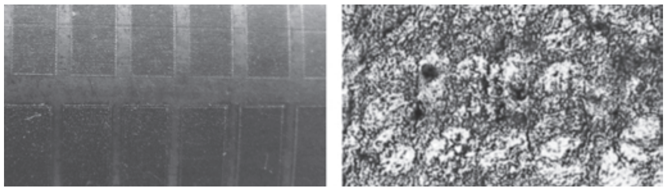


Figure 11. Visual aspect and a microscopic detail of processed CuAlSiC [18].

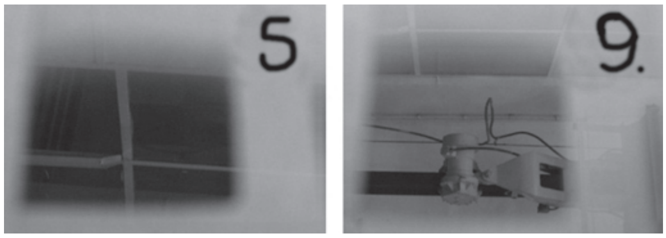


Figure 12. Metallic thin films realized by PLD (film thickness < 3μm).

For all three studied materials the roughness has a similar variation when varying the pulse repetition frequency, consistent with the variation presented in literature for metallic materials, and the highest increase in roughness was produced for CuAlSiC material (20 times bigger than of the base material).

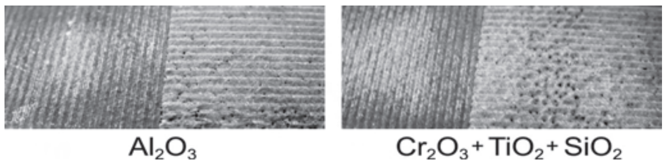


Figure 13. Samples of pulsed laser micro-alloyed thermal sprayed surfaces (thickness of sprayed layers < 500μm).

The other laser micro-structuring processes studied at ISIM Timişoara involved the laser micro-alloying of thermal sprayed microlayers and thin film deposition by pulsed laser processing. Figure 12 shows two sample of deposited metallic thin films obtained in an experimental vacuum chamber designed and realized for, while figure 13 shows two specimens of laser micro-alloyed thermal sprayed surfaces.

For both processes important results were obtained, e.g. microlayers with increased wear resistance, high hardness and with high resistance to cavitational erosion [19] and improved biocompatibility surfaces for implant applications [20].

2.3. Process control

In order to make the best use of the experience accumulated and the developed models related to laser welding of thermoplastics polymers [21,22] an integrated system for determining polymers laser weldability, real-time monitoring and control of the laser welding process was developed. The outline of this system, presented in Figure 14 required the designing and realization of various components and solutions to control the averaged output power of pulsed laser welding process as well as the characterization of the processing laser beam [23].

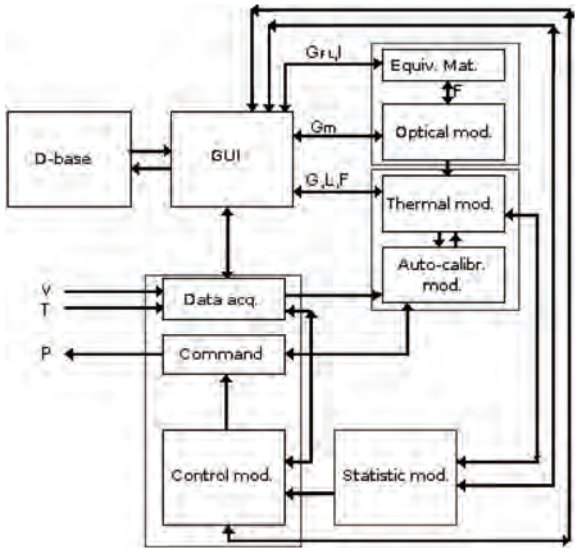


Figure 14. Schematic description of the integrated system [23]. (v – travel speed, T – temperature, P – laser beam (LB) power, G – geometric characteristics of the LB, m – material, I – value of the measured transmitted LB intensity, L – LB characteristics, F – material's thermo-physical characteristics)

Using the database component of the realized integrated system made it easier (in terms of necessary experimental volume) to develop technologies for welding dissimilar thermoplastic polymers by pulsed laser process [24], Figure 15.

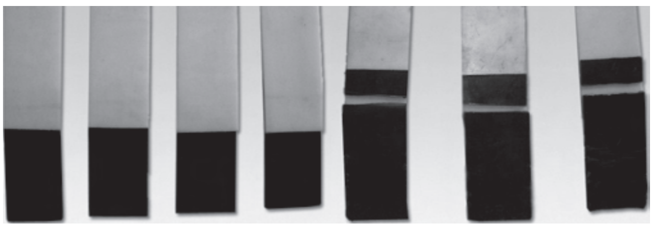


Figure 15. Pulsed laser welded dissimilar polymers (PEHD – quasi-transparent and PP – semi-transparent) and the results of the tensile testing [24]

Beside the development of the integrated system one should mention also the use of infrared (IR) thermography applied for studying a new hybrid welding process characteristics and as a offline control tool of the welding process [25].

2.4. Process development

One of the important RTD direction of ISIM Timișoara in pulsed laser micro-processing is the development of new hybrid processes for extending the process applicability and increase the welding productivity. The steps done in this direction involved: the design and realization of an experimental system for the development of LASER –TIG hybrid process (Figure 16) [26] and different laser-TIG hybrid assemblies (Figure 17), experimental work for process dynamics investigations and technological investigations as well as the development of sensors for controlling the process geometrical characteristics (e.g. laser beam – torch angle) [27].

The RTD work lead into fully characterizing a new laser-arc hybrid welding process – Pulsed LASER-(micro)TIG hybrid welding [28], as well as developing components which can be applied industrially for process control [29].

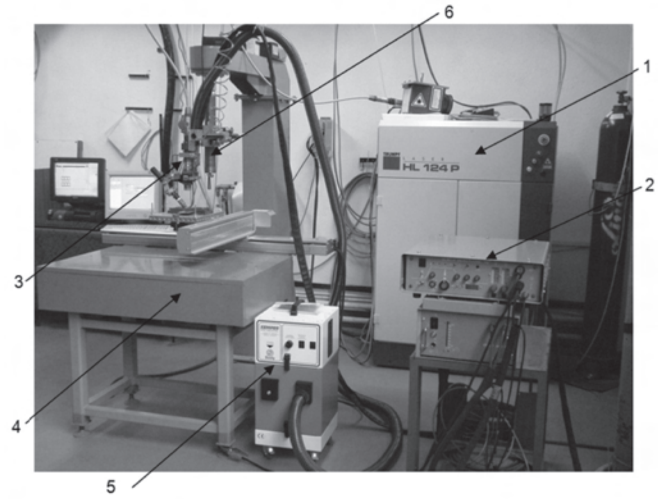


Figure 16. Experimental system.
(1 – laser Nd:YAG pulsed laser; 2 – TIG welding source; 3 – laser welding processing head; 4 – inertial table with xOy robot; 5 – exhauster; 6 – positioning system)

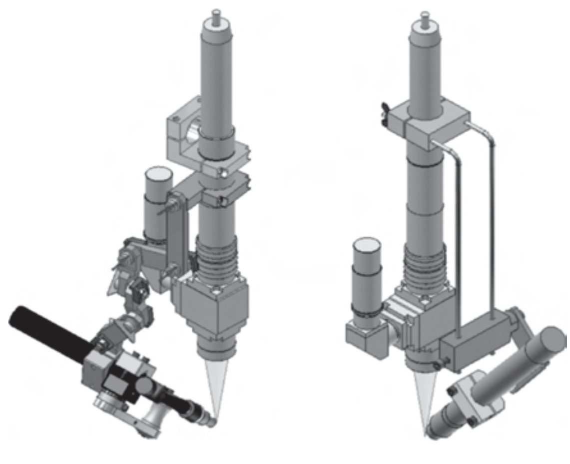


Figure 17. Two variants of hybrid assemblies [26]

Following the process development it was possible to develop highly efficient welding technologies as alternatives to the classical ones [30] with low linear heat input.

3. Conclusions

Since 1998, laser material processing is an active RTD priority for ISIM Timișoara.

The RTD related to the laser material processing performed at ISIM Timișoara was focused onto microprocessing and tackled various fields: from "classical" welding and cutting to new applications development (laser-arc hybrid processes), micro-structuring applications.

Beside developing of new processing technologies, the development of components and systems for process control was also one of the tackled RTD directions.

Laser processing of newly developed materials, e.g. micro and nanostructured metal matrix composites is also of interest and related to this, special attention is given to the inherent fumes emissions of laser processed MMC's.

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