SOME RESULTS CONCERNING LASER FINISHING OF TOOLS STEELS

Niculae Ion MARINESCU[1], Daniel GHICULESCU[1], Radu Dumitru MARINESCU[3], Cristina ANGER[3]

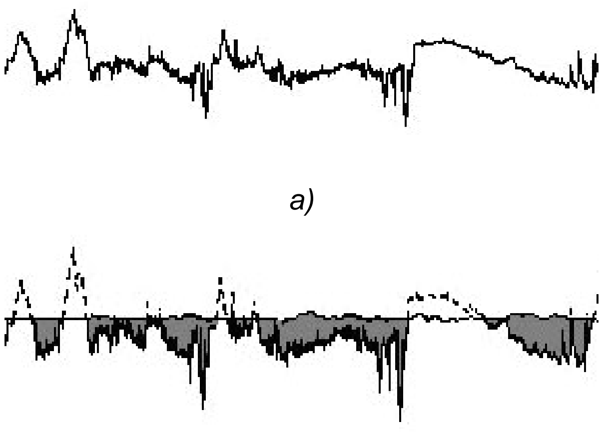
ABSTRACT:

The paper deals with preliminary researches concerning laser polishing machining of tools steels. Fundamental aspects and specific mechanism of material removal process are presented. The process is very intricate and difficult to be applied in order to achieve the expected results. The main parameter to be controlled is the energy amount, which is brought on machined surface, depending on two factors: feed speed of laser beam and power density. The paper deals with preliminary data obtained by polishing the *Orvar Supreme steel*, which is used, mainly, in the construction of injection molds. These early results represent a basis for large scale application of this new nonconventional technology.

KEYWORDS: laser, polishing, tool steel, roughness.

1. GENERAL CONSIDERATIONS

Laser polishing is a relative simple process but hard to be applied in order to obtain satisfying results because of complexity phenomena emerging during machining process. The process consists in superficial material - i.e. profile micropeaks - melting, using laser beam energy, for filling the profile micro-depressions with material corresponding to micro-peaks of the same surface. Thus, it can be noticed that initially having a high surface roughness (fig. 1.a), through thin material surface melting, leveling of micro geometry can be obtained (fig. 1.b) [1], [2].



a)

b)

a) before; b) after laser machining
Fig. 1. Surface profile

Primarily, in the polishing process, it is important that energy affects only the material superficial zone to be machined, respectively, profile micropeaks, because it is not intended to modify the workpiece macrogeometry. This means that a reduced amount of energy has to be concentrated in machining zone in order to avoid distortions of workpiece shape (in case of small wall thickness). On the other hand, excessively high energy density (close to that used for cutting or profound welding) would affect too great material thickness, melting and vaporizing a much deeper layer than it is required.

Consequently, the main parameter that has to be controlled is the energy amount that is brought on workpiece machined surface. This energy depends on two factors: *feed rate of laser beam* - at high rate of feed size, the laser beam covers a larger area of workpiece and the surface receives lower amount of energy and it is less heated - and power density, which, at its turn, is basically determined by two parameters:

- Total power – concentrated within the beam, which can be adjusted through opening index of generator.
- Beam dimension – or laser spot size, which mainly depends on laser type and focal distance. Energy distribution is determined by laser working mode, which is dependent on generator type.

In polishing process, in order to avoid melting a too deep layer, the amount of energy that is brought on machined surface, has to be diminished. Therefore, firstly, the feed rate is maximized, which leads to lowering of working time.

On the other hand, once the operating mode is established, two possibilities emerge: power decreasing or spot diameter increasing. These two options should have the same effect, i.e. the energy density decreasing, taking also into account the practical aspects of machining. Adopting the option of increasing the spot diameter, a greater width of workpiece surface can be finished at a single passage.

This fact is important, because for complete polishing of a surface, it is necessary the superimposition of beam passages. Thus, the greater is the spot diameter, the fewer number of passages on machined surface are required, as it is shown in fig. 2.

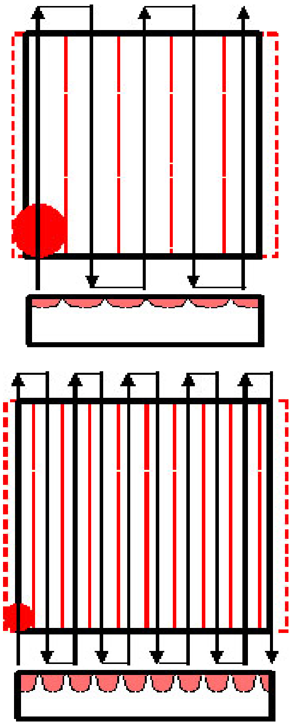


Fig. 2. Laser polishing with two different spot diameters

2. SPECIFIC MECHANISMS OF LASER POLISHING PROCESS

Nowadays, there are two mechanisms, which modify the machined surface during laser processing: Surface Shallow Melting (SSM) and Surface Over Melting (SOM). The principle of each mechanism is determined by a combination of power and feed rate as well as initial roughness of surface (R_a), before laser polishing [2, 3].

- **Surface Shallow Melting (SSM)**

The surface profile of a workpiece that can be seen with scanning electron microscope (SEM) comprises micropeaks and microdepressions. When a laser beam with enough energy attacks this surface, the micropeaks quickly arrive at the melting temperature.

If the feed rate of laser beam is great enough, then thin material layer will be melted. This molten volume will flow towards microdepressions due to gradient of superficial tension and gravity force, thus producing decreasing of microgeometry profile height.

For example, a metallic sinterized surface can be considered an aggregate of spheres, unified by diameters equal with mean diameters of initial powder (rough material). A micropeak corresponds to the upper part of a sphere and a microdepression matches the space formed by three tangent spheres.

When laser beam strikes the workpiece surface, the spheres surfaces included inside spot diameter attain the melting temperature. At the beginning of the melting process, the liquid flows from the upper part of the sphere towards the microdepression, leveling the surface profile.

- **Surface Over Melting (SOM)**

If the feed rate of laser beam is reduced, then an overheating of the surface occurs. Therefore, complete melting of contact surface with laser beam is produced, resulting increasing of initial roughness; this is the principle of SOM.

SSM produces decreasing of roughness through reducing the feed rate at working limit value. It the feed rate decreases, the interaction time between laser beam and machined surface grows, leading to SOM mechanism, i.e. roughness increasing.

As it is presented in fig. 3, laser beam movement determines flowing of molten material till solidification front, thus creating a kind of wave.

This phenomenon of material flowing is caused by difference between laser beam and solidification zone, as a result of beam movement.

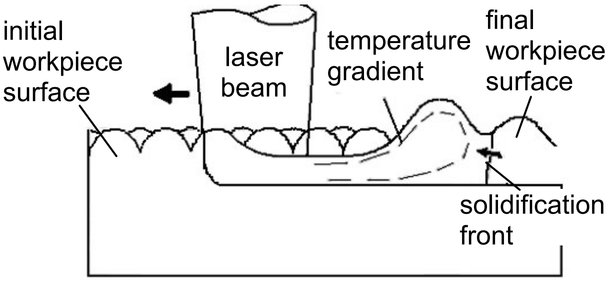


Fig. 3. Solidification front development

- **Other superficial phenomena**

If polishing laser is accomplished with oxygen presence, which has a certain pressure, the material from inside the melting zone has enough time to react, forming stable oxides. During solidification, it is possible that these oxides are segregated toward solidification front and affects the surface to be machined due to low density of these chemical compounds.

More over, diffusion into liquid takes place very fast, allowing formation of certain oxides, depending on temperature and oxygen partial pressure.

The result is forming of some relatively large plates, mixed into solidified matrix of base metal. Oxides because of forming entropy, grow in such shape, that lately present a smoother surface than the own matrix of material. In this sense, oxides have the trend to decrease the surface roughness [4,5].

3. MAIN ELECTROTECHNOLOGICAL PARAMETERS OF LASER POLISHING

At laser polishing, the main electrotechnological parameters of working mode are similar to other laser beam machining [8] as it is presented below:

- **Feed rate** (v_a)

It is the speed of feed movement of working head against workpiece, expressed in linear speed units of measure, generally in mm/min. This parameter is a measure of machining rate and determines the interaction time between heat source and workpiece. At lower speed, the thermally influenced thickness of material layer is greater and at greater speed, the effect is superficial.

- **Power** (P)

It is the relation between the energy of laser beam (usually measured in Joules) and time (measured in seconds).

Power density (q_P) is expressed, as concentration of the laser spot, on surface unit; $[q_P]=[W/cm^2]$.

- **Focal point position** (x)

The position of focal point is the distance [mm], from the workpiece surface till focal point where laser beam is convergent.

This parameter determines concentration of energy, which arrives on surface of material. If distinct, straight and transversal sections of laser beam along its length are considered, it can be noticed that highest energy concentration is located inside the zones situated next to focal point.

Taking into account the requirements of the process, the focal point is located at different distances from the surface to be machined. When laser beam is focused just on the surface, the energy delivered on the workpiece surface has maximum value and the machined area is minimal.

For different processes of laser polishing, the focal point can be situated in three distinct positions (fig. 4):

a) focalized (just on the surface to be machined);

b) above the surface to be machined (defocalized) – the most used variant;

c) beyond the surface to be machined (prefocalized).

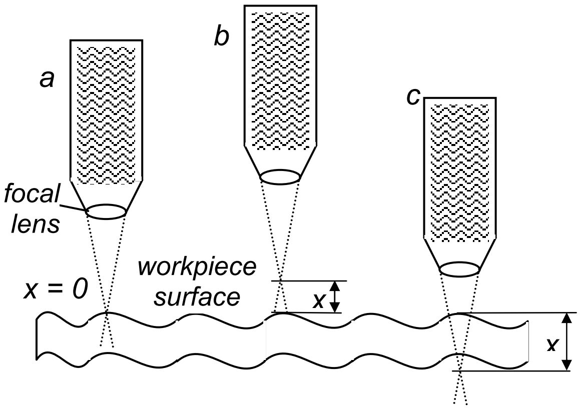


Fig. 4. Positions of focal point at laser polishing

- **Gas pressure** (p)

Every laser processing uses different gas types, which have distinctive parts within machining mechanism.

The aiding gas or process gas flows along the laser beam.

Depending on process and material to be processed, the gas can be active, like oxygen or inert gases, as argon or helium. The oxygen is used at metals cutting, based on exothermal reaction, which facilitates the metal melting. In this case, the gas pressure influences the evacuation of molten metal [6]. In other cases, an inert gas can be used in order to obtain a separation between fusion zone and external medium and consequently, controlled machining conditions. This is the case of laser polishing.

4. EXPERIMENTAL RESULTS OBTAINED AT LASER POLISHING OF "ORVAR SUPREME" STEEL

The Orvar Supreme steel is fabricated by Uddeholm [9], for tools used at high temperatures and pressures, and which is characterized by: high resistance to thermal shock and thermal fatigue, good strength at high temperature, excellent toughness and ductility in all directions, good machinability especially at polishing, excellent properties at hardening (dimensional stability at hardening).

These properties are very important particularly for tools subjected to thermal and mechanical fatigue stresses like: casting, forging and extrusion molds, injection of plastic materials molds etc.

The main elements from chemical composition of this steel are: C – 0.39%; Si – 1.0%; Mn – 1.4%; Cr – 5.2%; Mo – 1.4%; V – 0.9%.

The experimental determination was completed on a Robotiker installation, which contained a CO_2 laser ROFIN DC 025, with exit maximum power of 2500 W. The Robotiker Complex is a small part of the Technological Park of Zamudio, Spain.

The laser device has a Weidmüller 5" KN/MG working head with a ZnSe focalization convex lens, which provides a focal distance of 200 mm, obtaining a spot with minimum diameter of 0.4 mm.

The roughness obtained on the samples was measured by an electronic roughness device.

Taking into account the characteristics of laser polishing process, the variables taken in consideration at the polishing of the Orvar Supreme steel were: the exit power of the laser beam, the distance between the working head and the sample and feed rate (table 1). The surfaces submitted to laser polishing were previously machined by milling.

Table 1. Variables of polishing process

Polishing depth [mm]	Power [W]	Distance between working head and sample [mm]	Polishing speed [mm/s]
0.6	800-1500	22-37	1300
0.4	900-1900	22-37	1000-1400
0.2	800-1900	22-37	1300-1500
0.1	800-1900	27-37	1000-1400

For example, for the milled surface with the cutting depth, t = 0.6 mm, the initial roughness was R_a = 1.716 µm.

After laser polishing, the profile obtained is the one shown in fig. 5 (R_a = 0.864 µm).

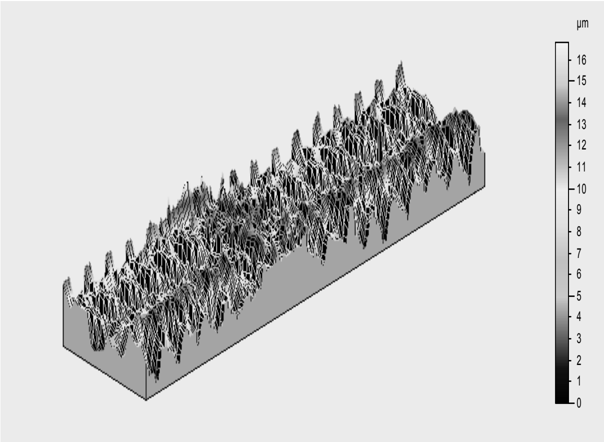
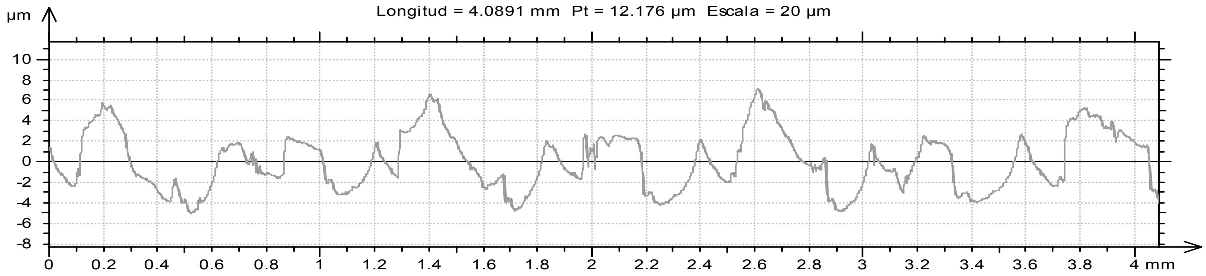


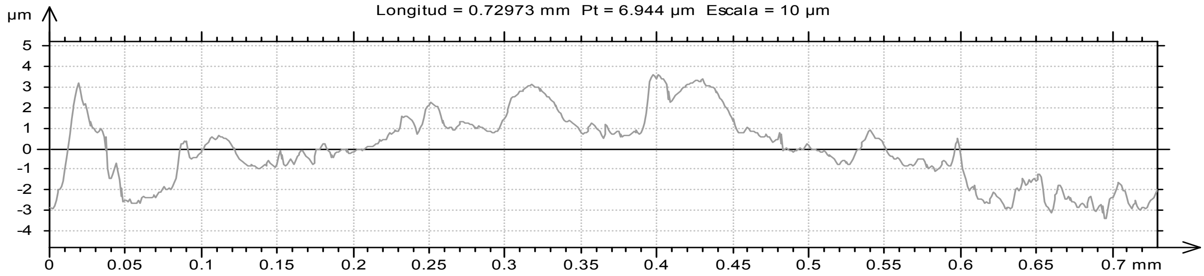
Fig. 5. The real profile of a laser polished section

The comparative study of the roughness before and after laser polishing was made by analyzing the profile in one section, according to the records presented in fig. 6 a, b.

Taking account of the aspects related to the main technological parameters presented above, some preliminary experiments are completed and their results are presented in table 2.



a) milled surface

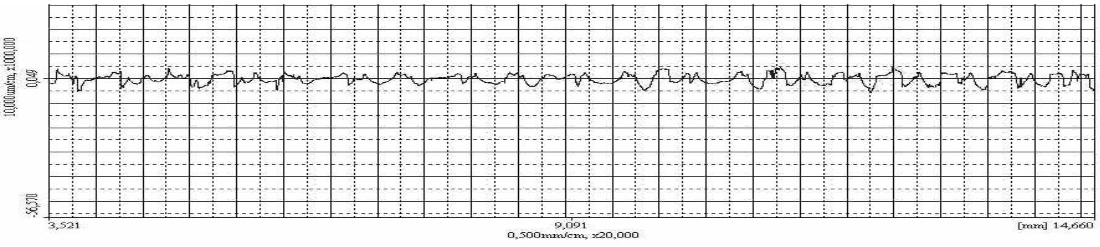


b) laser polished surface

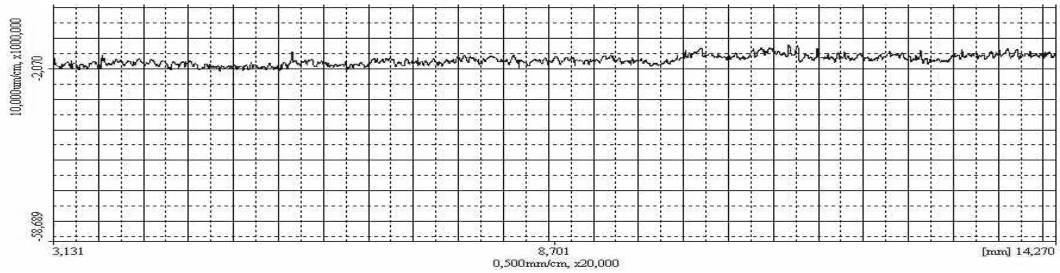
Fig. 6. The surface profiles before and after polishing

Table 2. Results obtained for milled surfaces by laser polishing

Depth of radial crossing a_e [mm]	Power [W]	Distance working head - sample [mm]	R_a initial [µm]	R_a after laser-polishing [µm]
0.1	800	22	0.756	0.356
0.2	1000	27	0.932	0.372
0.4	1200	27	1.299	0.583



a) The initial surface profile (t = 0,4 mm)



b) The polished surface profile

Fig. 7. Surface topography before and after laser polishing

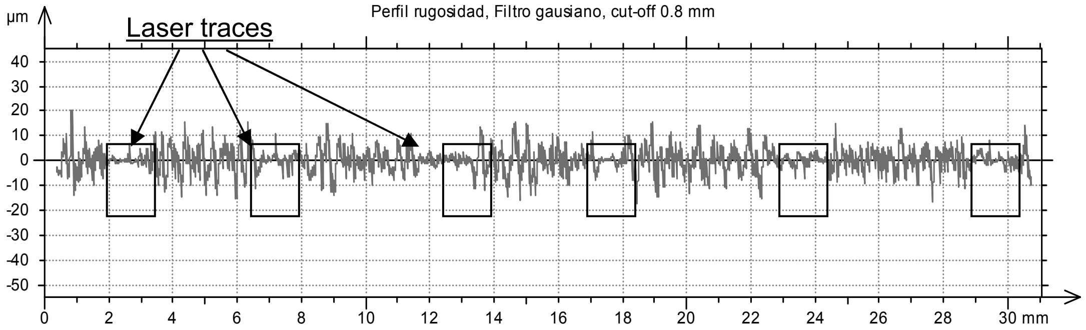


Fig. 8. Roughness improvement through laser polishing

Therefore, in fig. 7 a, b, the initial profile and the laser polished profile are presented. It can be noticed that the polished profile shows less obvious irregularities than the milled profile. The roughness improvement of the laser polished surfaces can be clearly noticed in fig. 8, through the measurements made on perpendicular direction on the polished traces.

5. CONCLUSIONS

Laser polishing of different surfaces of workpieces from tool steel is a machining, which is still in preliminary stage of researches, due to complexity of phenomenological and technological aspects that emerge during the process. From the preliminary results, it can be observed that the laser polishing process brings noticeable roughness improvements of the processed areas, up to 70 %, in the case of linear polishing traces of width up to 2 mm. The overposition of linear polishing traces in order to achieve complete machining of surface brings a decreasing even greater of the roughness, because, in these conditions, the Gaussian distribution influence of the laser beam is considerably diminished. The early results, related to machining rate as well as obvious improvements of surface quality, allow later development of consistent researches, a basis for large scale using of this advanced machining technology.

REFERENCES

[1] N. I. MARINESCU, *Tehnologii de prelucrare cu fascicule şi oscilaţii*, Editura BREN, Bucureşti, 2003.

[2] T. BURAKOWSKI, T. WIERZCHROW, *Surface Engineering of Metals*, Boston, CRC Press, New York, USA, 1999.

[3] J.A. Ramos, D.L. Bourell, J.J. Beaman, *Surface over-melt during laser polishing of indirect-SLS metal parts*, Materials research society symposium proceedings, 2003, vol. 758, pages 53-64;

[4] J.A. Ramos, D.L. Bourell, *Modeling of surface roughness enhancement of indirect-SLS metal parts by laser surface polishing*, Solid Freeform Fabrication Proceedings, 2001, pp 28-38;

[5] J.A. Ramos – Grez, D.L. Bourell , *Reducing surface roughness of metallic freeform-fabricated parts using non-tactile finishing methods*, International Journal of Materials and Product Technology,2004, vol. 1, 297-316;

[6] N. I. MARINESCU et al., *Procese de prelucrare cu fascicule şi jeturi*, Editura INOE 2000, Bucureşti, 2003.

[7] A. ZOUBIR, *Technology Developments Towards the Practical Use of Femtosecond Laser*, Micromaterial Processing 2005.

[8] D. GHICULESCU, *Prelucrări neconvenţionale*, Editura Printech, Bucureşti, 2004.

[9] * * * www.3dsystems.com; www.uddeholm.com

AUTHORS

1. Prof. Ph.D. Eng. Niculae MARINESCU, University POLITEHNICA of Bucharest, Romania, E-mail:n.marinescu@teh.prod.pub.ro, Phone:214029373.
2. Assoc. Prof. Ph.D. Eng. Daniel GHICULESCU, University POLITEHNICA of Bucharest, Romania, E-mail ghicu@teh.prod.pub.ro, Phone: 214029373.
3. Prof. Ph.D. Eng. Radu MARINESCU, University POLITEHNICA of Bucharest, Romania, Phone: 214029373.
4. M.Sc. Eng. Cristina ANGER, University POLITEHNICA of Bucharest, Romania, Phone: 214029373