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DEVELOPMENT OF A METHODOLOGY FOR IMPROVING THE TRIBOLOGICAL PROPERTIES IN DIE PROCESSING USING LASER SURFACE TEXTURING

METODA POLEPSZENIA WŁASNOŚCI TRIBOLOGICZNYCH NARZĘDZI DO WYKRAWANIA PRZEZ ZASTOSOWANIE LASEROWEJ OBRÓBKI POWIERZCHNI

Key words:

laser surface texturing, laser ablation, micro cavities, lubrication, friction, die wear, deep drawing tool

Słowa kluczowe:

teksturowanie laserowe, ablacja laserowa, mikrowgłębienia, smarowanie, tarcie, zużycie narzędzi, narzędzia do ciągnięcia

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Abstract

The purposes of this investigation were to measure the positive effects in the lubrication through the application of micro textures made by laser (Laser Surface Texturing). Different types of micro textured patterns were studied, which vary in the quantity of micro cavities, micro cavity diameters, depths of micro cavities, and surface density attacked by micro cavities. It was found that, compared with plain steel surfaces, laser texturing significantly reduces friction and wear.

INTRODUCTION

In the deep drawing tool process (**Fig. 1**), where some of the chassis used in different kind of cars are produced within the company METALSA, there are two main problems within the process. The first problem is the fracture of the deep drawing tool itself, and the second problem is the scratches on the pieces of the chassis. These two problems are caused due to the wear and friction in the deep drawing tool process.

These two variables are studied in the science of tribology. This science studies the friction between two bodies in movement, the wear as the natural effect of the friction, and the lubrication as an option to avoid the wear in the process.

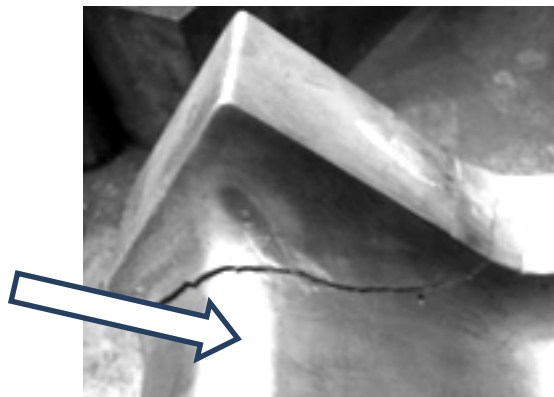


Fig. 1. Dies for drawing process showing fracture, the arrows shows the place where wear appears and LST can be applied [L. 1]

Rys. 1. Narzędzie stosowane w procesie ciągnięcia z widocznym pęknięciem, strzałką pokazano miejsce z widocznym zużyciem, w którym można zastosować obróbkę LST [L. 1]

In the need of constant improvement in the processes that involve wear and friction have led us to a new area of studies [L. 2], including searching for methods to decrease wear and friction. Previously, different methods have been

used to try to improve the quality of the process, e.g. different types of lubricants, different types of heat treatments, and coatings and new materials used for the deep drawing tools. However, our proposed method has never been used to achieve a reduction of wear and friction at METALSA.

Several studies have been made for creating innovative methods to decrease wear and friction, and one of these methods is called Laser Surface Texturing or also known by its initials as “LST” [L. 3].

The LST principle is to create micro sized cavities on the area of contact (**Fig. 2**). These cavities help to retain the lubricant, improving the lubrication between the two bodies. In addition, the small particles produced from the wear of the process are trapped inside the micro-cavities preventing scratches and friction [L. 3].

Many studies have been demonstrated that surface texturing has offered good performance in lubricated processes. The shape of the surface patterns can be catalogued in two different types: cavities or grooves [L. 4]. The cavities shapes can vary in many ways; they can be as simple as circles, ovals, and other complex figures [L. 5].

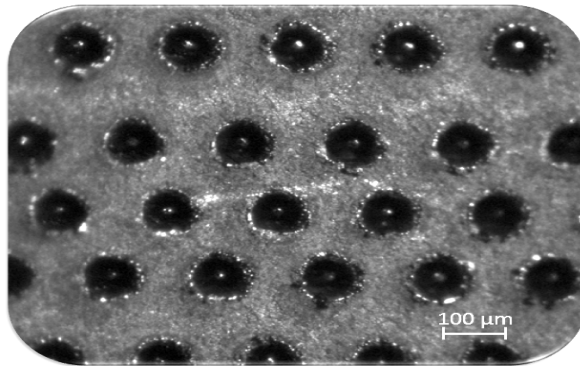


Fig. 2. Micro-cavities in a 16% density (100 μm)

Rys. 2. Mikrowgłębienia o gęstości 16% (100 μm)

The most important characteristic of the micro-cavities are the following:

- The depth of the circles,
- The width of the circles, and
- The density.

METHODOLOGY

Figure 3 shows the steps to of the development for this investigation. It began by looking for solutions to the problems in the deep drawing process of the Metalsa Company (**Fig. 1**). Then, selection was made of the proper laser and

the material for this investigation. The laser is an optic fibre doped with Ytterbium fibre while the material is an AISI steel D2, and the tribological tests were made to resemble the swaying movement that is found on the production line of the Company METALSA in order to get more accurate results.

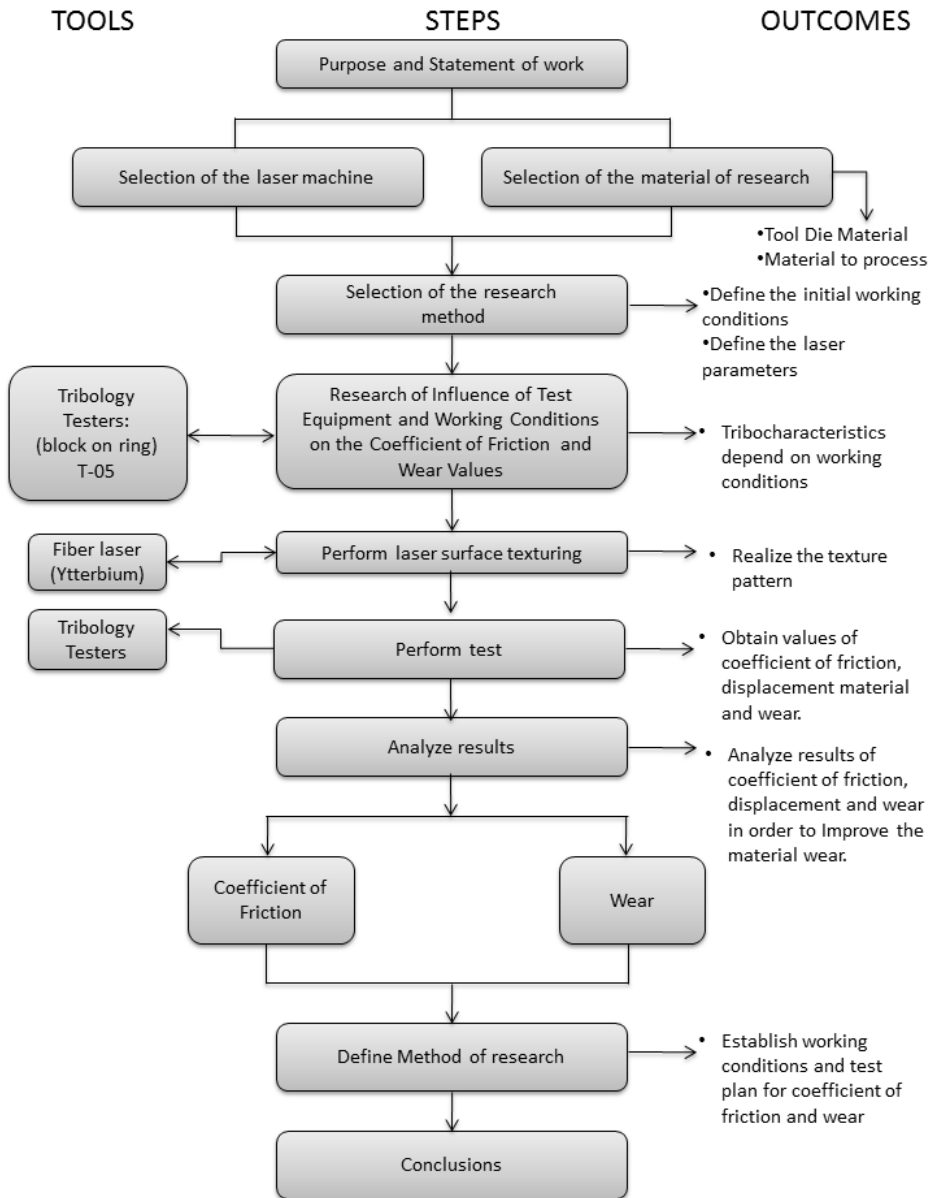


Fig. 3. Diagram for the project development

Rys. 3. Schemat realizacji projektu

EXPERIMENTAL SET-UP

Laser surface texturing

The material used was a D2 steel with the following chemical composition: 1.55% C, 0.35% Mn, 0.35% Si, 0.35% Cr and 11.50% Mo, balanced with Fe. The probes were made according the ASTM standard for a block-on-ring wear tester (T-05) (**Fig. 6**). The LST was applied in the concave surface of the probes using a laser marking machine "minilase" optical fibre doped with Yb Ytterbium (**Fig. 4**) using a wavelength of 1070 nm, a frequency of 15KHz, and a power range from 10 to 20Watts. The system uses a scan-head to deliver the laser pulses to the work piece in the programmed pattern.

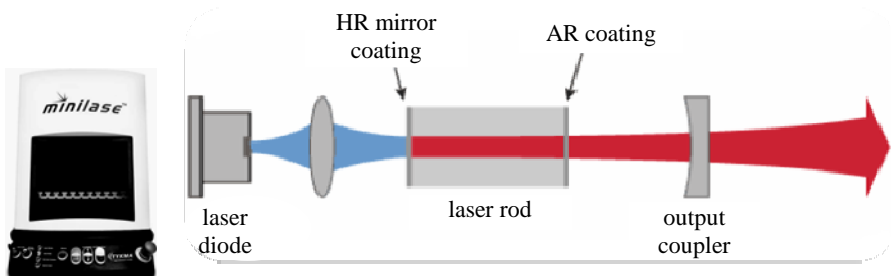


Fig. 4. Minilase Laser machine and principle of work [L. 6]

Rys. 4. Zasada działania lasera Minilase [L. 6]

The topography and profile of the micro cavities (**Fig. 5**) are detected by the use of a microscopy, which shows the optical micrographic of the laser textured surfaces of the material with a different spacing and density of the cavities.

The parameters that are used for the designation of the number of micro cavities were calculated using the formula:

$$\text{number of cavities} = \frac{\left(\frac{\pi \cdot D^2}{4} \right) \cdot (\% \rho)}{D}$$

Where D is the diameter of the cavity, "% ρ" is the density in **Table 1**, where each variable was performed with two different depths in the micro cavities of 15 μm and 50 μm.

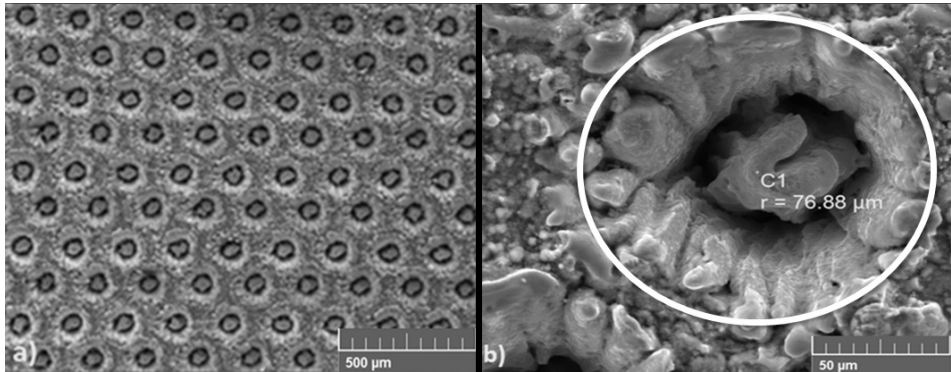


Fig. 5. a) General view of the sample surface with LST. b) Detailed view of the upper image. To appreciate the shape, the circle has a diameter of 76.88 µm

Rys. 5. Powierzchnia próbki po obróbce LST: a) widok ogólny, b) zdjęcie szczegółowe krateru z zaznaczoną średnicą 76,88 µm

Table 1. Parameters for the Development of LST

Tabela 1. Parametry obróbki LST

Parameter	Diameter (µm)	Density (%)
High	80	16
Medium High	80	8
Medium Low	130	16
Low	130	8

The percentage of density refers to the area that is covered by the micro-cavities in relation to the total surface area of contact, and it is assumed to be distributed over the entire contact surface [L. 3].

In this article, an investigation is made about many variables: micro cavities (where the density is an important characteristic), the diameter, and the depth. The development of tribological tests included the movement that represents deep drawing tools on a production line.

Tribological Testing

The T-05 Block-on-Ring Wear Tester (**Fig. 6**) was designed to determine the lubricating properties of solid film lubricants, lubricating fluids, and greases.

In this experiment, the tribological system is integrated with a stationary block made of the material required and applies pressure with a load P against the ring, which rotates at the speed defined and oscillating at the frequency and amplitude determined.

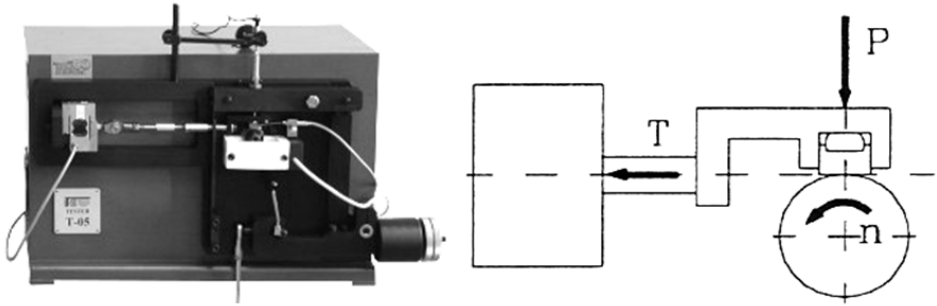


Fig. 6. T-05 Block-on-Ring Wear Tester [L. 7]

Rys. 6. Stanowisko badawcze T-05 typu rolka-kłócek [L. 7]

In this test, it is necessary to consider the actual operating conditions of the process that need to be duplicated to get more precise results. Therefore, for the tests, the original operating conditions will be changed, the ring of the test normally rotates 360° , but for this case, the test ring will only rotate 90° in order to try to reproduce the drawing process movement.

The test is done using a probe where the area of contact in the block fits against the ring (surface contact) (**Fig. 7**).



Fig. 7. Block on ring probe test [L. 7]

Rys. 7. Rolka i kłócek stosowane w badaniach [L. 7]

During experimentation, the frictional force and the total linear wear of the samples were measured. The durations of the tests were 900 or 3600 seconds, depending on the test parameters.

There are two different ways to evaluate the results of this test.

- Using the graphs given of displacement and friction force, and
- Measuring the marks of wear in the block.

The first graph (**Fig 8**) indicates the frictional force in the tribological system, which can be used to calculate the friction coefficient. To analyse the frictional force, it is recommended to use the average of all points.

The second graph shows the vertical displacement of the samples due to wear. It is necessary to take two reference points; the first is where the displacement begins to stabilize, and the second point is the greatest value of the graph. Extremes are excluded in the graph, because there is a probability that the peaks are caused due to an external abnormality, but this does not influence the test results.

RESULTS

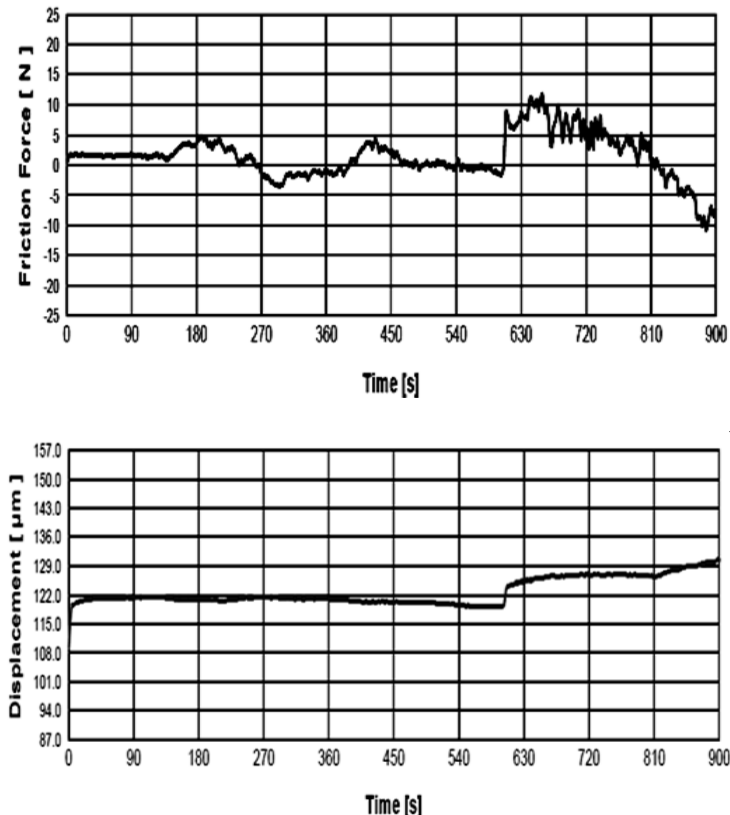


Fig. 8. Example of the results given by the software of the tribological machine T-05, the first graph is the friction force (N) and the second is the displacement (μm)

Rys. 8. Przykładowy wynik badania uzyskany za pomocą oprogramowania stanowiska T-05, wykres pierwszy to siła tarcia [N], drugi – zużycie próbek (μm)

RESULTS AND DISCUSSIONS

Tribological tests

Tribological tests were performed while individually changing each variable. The results are showed in **Table 2**. Variables from A to G have LST and variable H does not have LST.

The results obtained from the tribological test were analysed, and it was found that variable B is the one with less wear, while variable H was the one with the most wear, being the only variable that was not treated with LST. The friction coefficients were also analysed, and once again variable B is the one with the less friction present, while variable A is the one with the most friction. This can be observed in **Fig. 9**.

Table 2. Parameters and results of different variables with LST

Tabela 2. Zestawienie wyników pomiarów dla próbek poddanych obróbce LST

Variable	Speed (rpm)	Load (kg)	Diameter (μm)	Depth (μm)	Density (%)	Displacement (μm)	Friction (N)
A	250	15	80	15	8	8.121	5.204
B	250	15	80	15	16	6.211	0.888
C	250	15	80	50	8	8.334	4.067
D	250	15	130	15	8	6.898	3.064
E	250	15	130	15	16	7.915	3.212
F	250	15	130	50	8	7.163	3.211
G	250	15	130	50	16	6.394	2.825
H	250	15	N/A			12.703	4.425

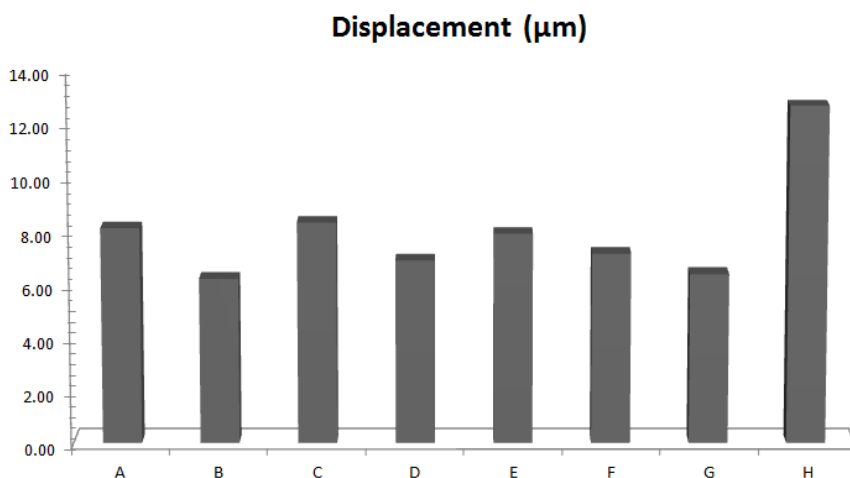


Fig. 9. Displacement results obtained from tribological tests

Rys. 9. Wyniki zużycia z testów tribologicznych

With the previous results, tests with extreme conditions (increments of 10 kg every 600 seconds up to 3000-second maximum) were performed for variables B, G, and H. The objective of these tests was to know the limit of functionality of LST. These tests yielded the following results (**Table 3**).

The results of **Table 3** and **Fig. 10** demonstrate that, when LST is used, it is possible to double the duration of the tests in a considerable magnitude (B and G variables managed 50 kg extra support and continued to demonstrate a better reduction in displacement and the coefficient of friction).

Table 3. Parameters and results of variables B, G and H.

Tabela 3. Zestawienie wyników pomiarów dla zmiennych B, G i H

Variable	Speed (rpm)	Load (kg)	Diameter (μm)	Depth (μm)	Density (%)	Displacement (μm)	Friction (N)
Test duration 3000s							
B	250	15	80	15	16	15.23	13.795
G	250	15	130	50	16	6.563	6.014
Test duration 1550s							
H	250	15	N/A			11.85	5.436

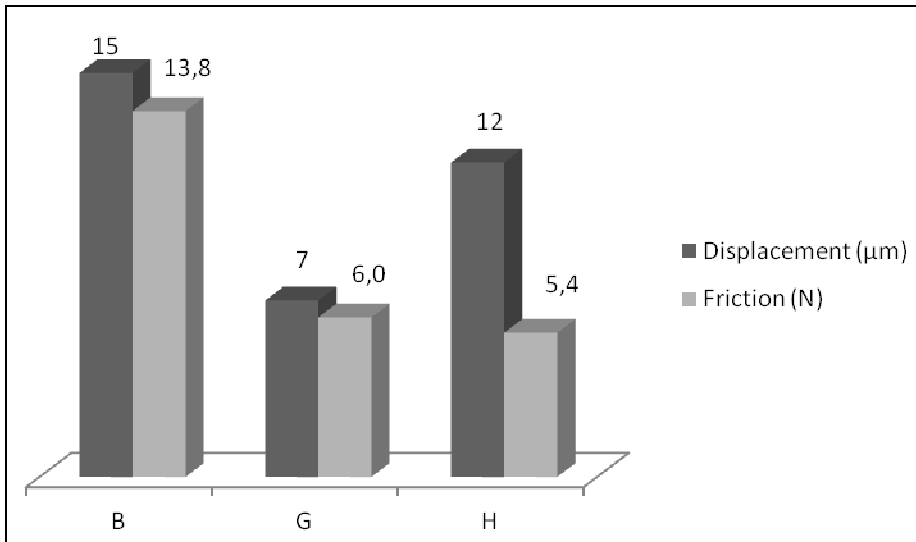


Fig. 10. Displacement results obtained from variables B, G, and H in tribological tests

Rys. 10. Wyniki zużycia uzyskane w testach tribologicznych dla zmiennych B, G i H

CONCLUSIONS

Based on past results, the three variables of greatest importance, then compared within LST, which are the diameters of the circles, were the depth and density. The effects of the depth of the cavities were compared, giving the result that with a depth of 15 micrometres there is less wear, while with friction the depth of 50 micrometres has less friction. The effect of density was also compared, showing that, to reduce wear and friction, it is recommended to use a density of 16%. In relation to the diameters of the cavities, it was found that, with a diameter of 130 micrometres, the wear was less and this was the same for friction. Therefore, if less wear is desired, it is necessary to have a depth of 15 micrometres and a density of 16% and diameters of 130 micrometres. The results indicate that variable B has two of the characteristics mentioned, which are the depth and density of cavities. It was found that the three best variables were B, D, and G, and these are the ones that suffer less wear and have a lower friction.

RECOMMENDATIONS:

- a) Perform more test in order to optimize the density.
- b) Test the effects of nanoparticles in the lubricant.
- c) Do tribological testing using high-speed motion.
- d) Suggest pilot test on the production line of dies.

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Streszczenie

Propozycją niniejszej pracy jest zbadanie pozytywnego efektu smarowania poprzez wykonanie za pomocą obróbki laserowej mikrowgłębień na powierzchniach kontaktowych. Przystudiuwano różne typy mikrowgłębień i różne wzory tekstury, liczbę mikrowgłębień oraz ich wymiary, jak również ich dystrybucję na powierzchni. Efektem tej obróbki było zredukowanie tarcia i zużycia w porównaniu z płaskimi powierzchniami stali.