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WEAR TESTING MACHINE BY LASER BEAM ABLATION PATENT NO 24013 EGYPTIAN PATENT OFFICE

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Abstract: *Wear testing machine by laser ablation has been considered as a new method of wear testing which overcome the problems of old machines and systems. In this case, wear rate has occurred due to ablation by laser beam and test sample transformed from solid state to gas state directly (sublimation) and avoid relative movement and loss of material between sample and disk or plate. The different operation conditions such as temperature, chemicals, environmental conditions and different types of stresses has been considered. The new machine consists of two main parts optical and mechanical parts. The optical parts which include ultraviolet laser source, optical filter, lenses to concentrate the beam and manhole of laser beam to the sample tested in the control room. The mechanical parts includes The insulated chamber , dead weight , variable speed motor, sample holder, temperature and pressure sensor and ph meter. Mechanism of operation depend mainly on Ablation process which is removal of material from the surface of an tested object by vaporization .Ultraviolet laser beam is used as source of energy required for ablation process to avoid thermal effects. The new technique is suitable for all kinds of materials such as metals, alloys polymers, ceramics and composites in any shapes and sizes. The main factors affecting the new techniques are divided into factors related to the laser beam characteristics and factors related to material properties, the material properties include the surface roughness, thermal conductivity, specific heat ,density and mainly latent heat of sublimation.*

Keywords: *wear, ablation, sublimation, ultraviolet, laser.*

1. INTRODUCTION

The Pin on Disk Tribometer incorporates many features such as direct weighting. One important feature of all the Tribometers is that the wear automatically stops when a specified coefficient of friction reaches a threshold value, or when a desired number of rotations are completed [1]. All tribometers can be equipped with a depth measuring sensor for real-time display of depth information which is important in studying the time dependant wear properties[2],[3].

It is designed as a frictionless force transducer. The deflection of the highly stiff elastic arm, without parasitic friction, in the friction track. The wear and friction coefficient is determined during the test by measuring the deflection of the elastic arm and weight loss.

The Linear Tribometer Including calculation of a friction coefficient for both forward and backward movements of the stroke, generating data on Hertzian pressure via its software package, and static partner and sample wear rates. The reciprocating technique is also very useful for studying the variation over time of the static coefficient of friction - as opposed to the kinetic coefficient measured with the Pin-on-Disk geometry. Most contact geometries can be reproduced including Pin-on-Plate, Ball-on-Plate and Flat-on-Plate (others on request) [4].

A special heating module using a differential arm which compensates for changes in the temperature of the load arm can be attached to the standard tribometer allowing lubricated testing up to 150°C, The heating module uses a controlled temperature liquid, regulated to an accuracy of 0.1°C to heat the sample [5],[6].

Features of the Pin-on-Disk Tribometer

- Direct dead weight (weight directly over the pin) gives much higher stability [7].
- Precisely calibrated friction and wear measurements [8].
- Stable contact point with no parasitic friction.
- Pin, Ball and Plate on Plate testing.
- Automatic switch off at threshold coefficient of friction or total number of turns
- Plexiglas enclosure for testing in liquids, controlled humidity or inert gases[9].
- Testing compatible with ASTM G99 & DIN 50324 [10] :[16].
- Continuous wear depth recording (optional) [17].
- High Vacuum Testing (optional) [18].

Disadvantages of conventional wear techniques

1. The plate or disc must be changed every experiment, it is considered as expensive and relative technique [19].
2. Pin on disk and pin on plate are very complicated techniques [20].
3. The conventional method of wear detection such as pin-on-disk or pin on plate tribometry have only standards for specific applications [21].
4. The maximum load is 46N at frequencies up to 8Hz (25Hz optional) with a stroke range up to 60mm and a sliding radius of up to 35mm [22].

Liquid Heating Option up to 150°C can be installed on existing Pin-on-Disk and Linear Tribometers which is a very limited temperature range [23],[24].

2. EXPERIMENTAL WORK

An invention is developed to measure wear by laser ablation techniques instead of conventional machines (Pin on disc) or (pin on plate). The main component of the new machine is shown in fig.1. Wear coefficients for the tested material are calculated from the volume of material lost during the ablation process. This simple method facilitates the study of friction and wear behavior of almost every solid state material combination with or without lubricant. The technique can be used for liquid substances with special design of sample holder. Furthermore, the control of the environmental parameters, temperature, humidity and lubrication in the insulated test chamber allow a close reproduction to the real life conditions of practical wear situations. While the control test parameters such as laser power , fluence, number of pulses , repetition rate, speed of sample rotation, applied load and test time can introduce exact value of wear coefficient [22]. Fig.2 shows the steps and the main factors affecting the new wear measurement system by laser ablation.

The mathematical relation for The ablation rate (nm/pulse)

$$\chi = \text{ablation rate} = \alpha^{-1} lin(\phi_{inc}/\phi_T) \qquad (1)$$

$$\phi_T = E/\alpha(1-R) \qquad (2)$$

Where

E - (Threshold) energy density,
χ - ablation rate (nm/pulse),
R - reflectivity,
α - optical penetration depth,
ϕ_{inc} - incident fluence,
ϕ_T - threshold fluence.

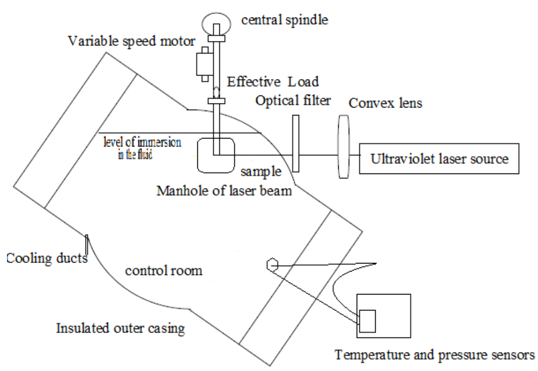

Figure 1. Wear testing machine by laser ablation

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2.1 The main components of the wear testing machine by laser ablation

A) Optical parts

Laser source is the main utensil in the new technique, high power ultraviolet laser concentrated in a small area, using plan - polarized source incident on the surface at Brewster's angle to increase the amount of absorbed energy and achieve the ablation condition to change the state of the material from solid to vapor directly (sublimation), The main four parts in the optical system are:

1. Ultraviolet laser source,
2. Optical filter is used to eliminate defects and chromatic aberration,
3. Optical elements collected and focused laser beam, and
4. Convex lens (optical parts used in the focus of the laser beam).

B) Sample holding and movement

The new technique reproduces the reciprocating motion typical of many real world in situ mechanisms and also simulate the amount and type of applied pressure in static and dynamic load, sample holder and movement system consists of four parts:

1. The central spindle,
2. Variable speed motor to rotate the test sample,
3. Mask of the samples dipped in the control room, and
4. Effective Load.

The central spindle is loaded onto the test sample with a precisely known weight. The pin is mounted on a stiff lever, insures a nearly fixed contact point and thus a stable position in front of the laser beam. Variable speed motor is used to rotate the test sample with the same speed similar to the in situ operation conditions.

C) Control unit

The new wear measurement technique with laser ablation is supplied with a insulated chamber enclosure so that controlled atmospheres such as varying humidity or media with specific composition and PH can be used. Specialized control of the test chamber have been developed for high & low temperature operations, reciprocating motion and high and low vacuum testing are also available.

- Insulated outer casing of the control unit.
- The level of immersion in the fluid sample tested.
- Temperature and pressure sensors related to the control unit.
- Manhole of laser beam to the sample tested in the control room.

D) Environmental condition control

The new technique can be equipped with a heating and cooling utensils for testing under a wide variety of temperatures and environmental conditions so the system include:

1. Pipes to push acidic, basic or liquid to submerge the samples in operatin conditions,
2. Level of operating conditions,
3. Heaters to control the test conditions, and
4. Cooling ducts.

A convenient intermediate temperature solution for tribology work can be used in the new technique, The temperature range between the standard room temperature and the high temperature. With this option, the in-situ conditions for a range of deposition technologies, such as ion beam sputtering PVD and CVD, which use quartz lamp heating to attain similar temperatures, can be reproduced. This range of temperature is also ideal in the study of biomaterials where body fluid temperatures range +/-37° C. The new technique is suitable for high temperature services and carcinogenic applications, it is also ideal for space, aircraft and almost all engineering and building applications.

2.2 The factors affecting the process

When the laser strike the metal surface during wear test by laser ablation, the energy is absorbed and distributed along the tested sample. The variation of temperature with distance for different metals such as Iron, Tin , cupper , Aluminum, zinc and lead at the same laser source, clarify the rate of various properties including the specific heat , the latent heat of sublimation (evaporation) , and the variation of various parameters such as density, thermal conductivity, thermal diffusivity and reflectivity.

Fig.3 shows the temperature variation with depth at the beginning of ablation process at the surface for different metals with different thermal characteristics at the same laser irradiation conditions same laser power, fluence, repetition rate, number of pulse and duration time.

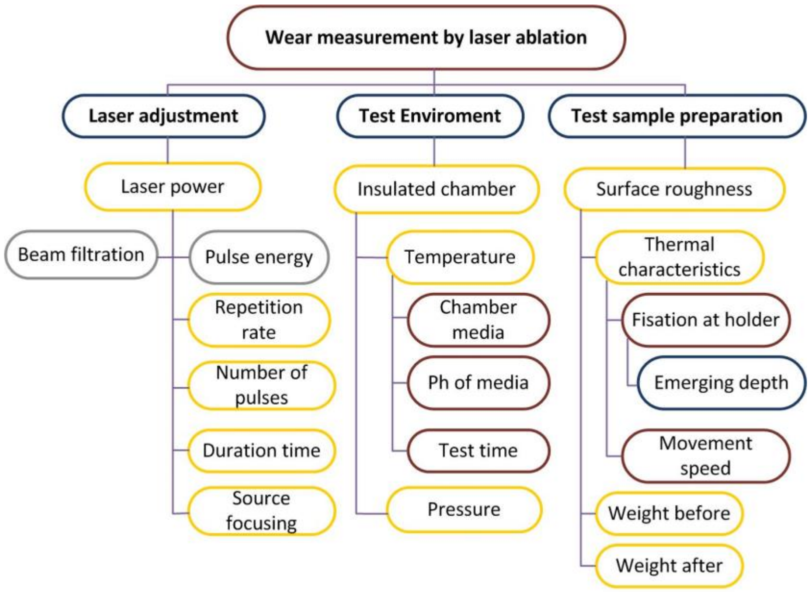

Figure 2. Steps of wear measurements by laser ablation technique

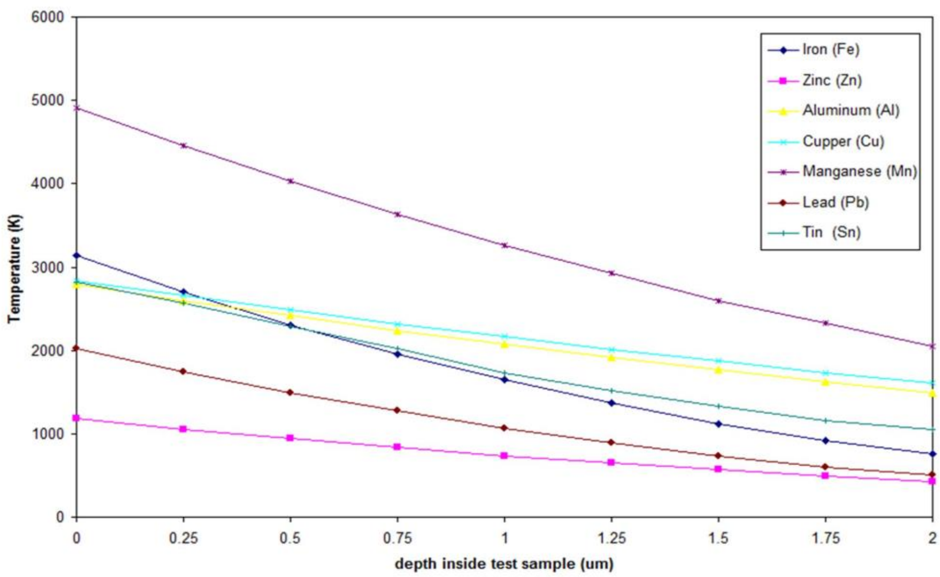

Figure 3. The temperature variation with depth at the begining of ablation process at the surface

The main parameters in the ablation process is the variation of velocity , ablation depth and time at the solid -vapor interface, which is also affected by the thermal characteristics of the tested materials at the same laser irradiation conditions. Table.1 shows the ablation characteristics during wear test for some pure metals, The variation in the ablation parameters is shown in both fig 4 and fig 5 respectively which show the variation in ablation depth and ablation velocity for different metals have different thermal characteristics.

Table 1. The ablation characteristics during wear test for some pure metals

Metal	Evaportion depth,μm	Time, Sec	Velocity, m/sec
Iron (Fe)	38.8	$9.42\cdot10^{-4}$	412.47
Zinc(Zn)	70.3	$41.6\cdot10^{-4}$	169.03
Aluminium (Al)	30.8	$4.2\cdot10^{-4}$	681.24
Cupper(Cu)	27.16	$2.5\cdot10^{-4}$	1068.79
Manganese(Mn)	25.5	$9.4\cdot10^{-4}$	270.9
Lead(Pb)	47.2	$17.1\cdot10^{-4}$	275.56
Tin (Sn)	10.2	$0.72\cdot10^{-4}$	1418.5

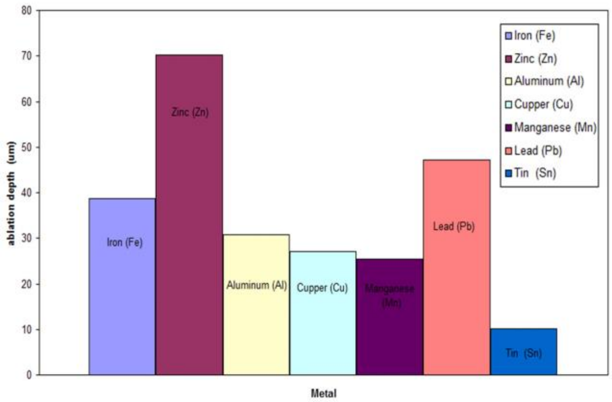

Figure 4. The abltaion depth of different metals exposed to the same laser source

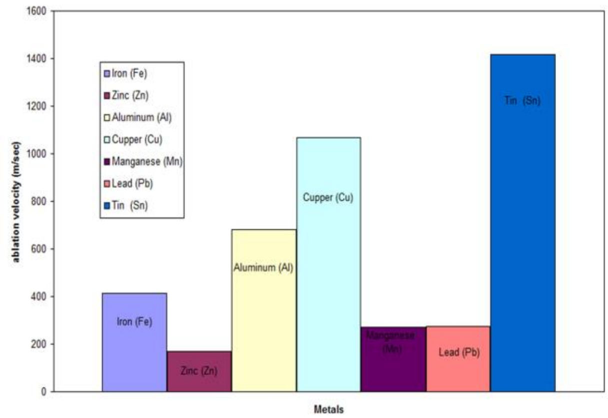

Figure 5. The abltaion velocity for different metals during wear measurement

The increase in ablation depth is related to the decrease in the ablation velocity at the solid -vapor interface and vice verse, so when comparing the wear rate of different materials the new technique is seem to be ideal for this type of comparison, which can not achieved in the conventional techniques.

2.3 Mechanism of operation

During wear test by the new method ablation is occurred from the surface of test sample. Ablation is removal of material from the surface of an object by vaporization , process begin when the amount of laser energy absorbed is more than the enthalpy of sublimation, or heat of sublimation, which is the heat required to change one mole of a substance from solid state to gaseous state at a given combination of temperature and pressure, usually standard temperature and pressure (STP). Fig.6 shows the mechanism of wear measurement by laser ablation. The insulated chamber which include the test sample may be considered as a closed system of fixed composition in solid state undergoing a temperature change from room temperature or preheat temperature to the sublimation (evaporation) temperature at constant pressure

$$\Delta H = H(T_{evap},p) - H(T_o,p) = dh = Cp\, dT = Qp \qquad (3)$$

Where Qp is The amount of heat required to raise the temperature of the system from room temperature T_o to the evaporation temperature T_{evap} , fig 7 shows the temperature distribution inside the tested sample just before the ablation process begin. after that the amount of laser energy equal to the latent heat of sublimation evaporation is also absorbed, then the ablation begin on the sample surface. The loss of energy due to scattering and reflection from the sample surfaces must be included in the total energy absorbed by the sample for ablation process. After removal of material from the surface the losses due th reflection is dropped down and scattering of energy in the ablated hole work as energy trap increase the amount of energy absorbed so the ablation rate increase. During the ablation volatile gaseous fragments are found and help to move larger molecular fragments away from the surface. The process begin with laser absorption up on the sample surface, surface reflectivity has pronounced effect up on the process rate, ablation takes place after the laser pulse is over so that shielding of pulse energy by the generated plume does, the absorbed energy per volume must exceed (Threshold) density E_T, re-deposition does not occur significantly.

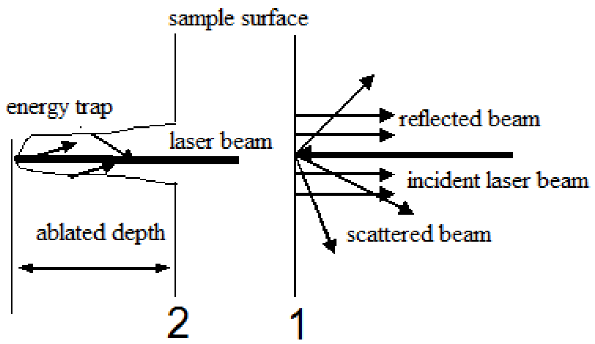

Figure 6. The mechanism of wear measurement by laser ablation

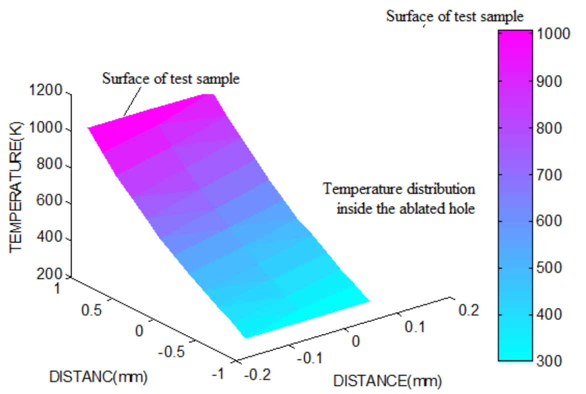

Figure 7. The temperature distribution in the ablated hole during wear test by laser

The method of exploitation

1. Can be used to measure the wear rate regardless of the thickness of the test sample and suitable for thin films.
2. Can be used to measure the absolute wear rate in metals and various materials while the old methods measure relative wear rate between test sample and disc or plate.
3. The laser beam's ability to pass through various liquids makes the machine measure wear rates of materials submerged in liquids or media in different conditions similar to operating conditions.
4. The machine can be used as an effective way to compare the resistance of materials varying in hardness and durability.
5. The machine can be used to measure the new materials with unknown hardness and composition.
6. Suitable for high temperature services materials and low temperature services materials which may be deformed in normal methods laser wear testing machine become the perfect.
7. The new method is suitable for treated materials regardless of the method of treatment (non-known hardness surfaces with high resistance).

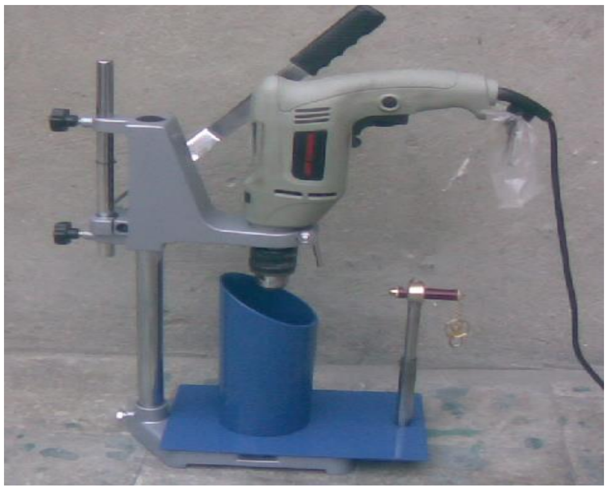

Figure 8. The prototype of the wear testing machine by laser ablation

8. The machine is used to test strong materials of great firmness and resistance, which cause high wear rates in the disk when tested with conventional methods. Fig.8 shows the prototype of the wear testing machine by laser ablation
9. Can be used in studying the time dependant wear properties.

Advantages of the invention

1. Replace the disk, or the plate at a regular machines with the laser beam.

2. New test machine is suitable for all types of materials and does not depend on the form or the shape of the sample
3. The laser beam has a uniform intensity and direction throughout the duration of the experiment, so the results are accurate and absolute values
4. Laser beam can be directed by the optical parts in the horizontal, vertical or diagonal directions, so any part of the test sample can be measured.
5. Thin film, electronic materials and other materials that are difficult to test by standard methods can be tested easily after the selection of the suitable laser wavelength and intensity.
6. The test condition can be adjusted at any temperature and there is no limitation related to test conditions.
7. Comparing the wear rate of different materials the new technique is seem to be ideal

3. CONCLUSION

1. The new wear testing machine depends on the interaction of lasers with matter.
2. The energy required for measuring wear rate by the new technique must be more than the latent heat of sublimation added to the dissipated energy due to reflection and scattering added to the energy required to heat the sample to evaporation temperature.
3. The rate of the process (time required for testing wear by new technique) is function of testing material characteristics such as diffusivity, specific heat , thermal conductivity and density.
4. The surface of the testing sample must be flat and relatively rough to avoid dispersion of energy due to reflectivity.
5. Cold laser beam in the range of ultraviolet lasers are recommended in the new technique to avoid thermal effects which has side effects on the quality of the process.

RECOMMENDATION

The new wear measurements technique must be included as the standard test method for measuring wear coefficient in the ASTM, DIN, BS, Egyptian standard and all international standards.

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