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On the Possibility of Laser Stripping of Communication Cables with Low-Power CO_2 Laser

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***Abstract* - Laser engraving is one of the most commonly used laser procedures for interacting with laser material. The speed, ease of use and high precision make it an attractive process for use by manufacturers and for removing insulation from various cables. Cable stripping is a particularly common operation in aeronautics. The aircraft is equipped with several hundred kilometers of cables to control and operate the various systems of the aircraft and most of these cables must be stripped at both opposite ends to allow the cable to be connected to different terminals.**

This report examines the possibility of removing polyvinyl chloride (PVC) insulation from telecommunication cables of different colours and thicknesses up to 600 [μm]. The experimental measurements of the study were performed with a low-power continuous CO_2 laser system. The main functional dependence of the width and depth of the ablation zone on the main technological parameters, such as the average power and the processing speed, have been experimentally studied. The zones of laser impact are observed with a laser microscope. The graphic dependencies are analyzed in order to determine the optimal working intervals.

The analysis aims to help solve problems related to the application of small diameter communication cables in the production of various communication devices and components for the needs of industry.

Keywords* - *ablation, cable, CO_2 laser, polyvinyl chloride

I. INTRODUCTION

Polyvinyl chloride is one of the major types of plastics, which is widely used in various industries like electrical, automotive equipment, packaging, construction, aeronautics, and applications such as windows, flooring, bottles, pipes, fittings, cables, etc. [1]. At the global level, demand for PVC exceeds 35 million tonnes per year, and it is rated second only after polyethylene as volume leader in the plastics industry [2]. Due to its low cost and good dielectric and processing properties, PVC is one of the most widely used insulating materials [3]. It also has stable chemical properties, has excellent fire resistance due to the presence of chlorine, is easily process able, has good insulation and dielectric performance, and is environmentally friendly [4,5].

Nowadays in manufacturing, the ability to strip insulation of various materials and materials from cables or wires is very important. For “state-of-the-art” applications it is necessary to be able to strip insulation layers with high precision and efficiency, without damaging the conductor. For copper (CU) cables laser wire stripping mechanisms achieve this by their ability to selectively remove insulating material while leaving copper intact. It is very important to find a balance between the intensity of laser radiation and the preservation of cable characteristics to achieve an optimal cable stripping process.

One of the most commonly used laser types for wire-stripping systems is the CO_2 laser. CO_2 lasers play a large role in the laser-material processing industries. CO_2 laser offers good beam quality and low cost per watt. Numerous discrete output wavelengths from 9 to 11 microns in the far-IR spectrum. Specific wavelengths can be selected with the use of isotopes in a laser gas mixture. Radiation in this wavelength is strongly absorbed by a large amount of commonly used materials including PVC [6].

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The CO_2 laser beam does not damage the conductor part of the CU cable, because copper is very reflective to the CO_2 laser beam and has high thermal conductivity, but the insulating materials tend to be highly absorbing. As the laser beam passes through the cable, it cuts precisely through the insulation, which which allows easy removal of the insulating layer of the cable [7].

Martnyuk has researched the usage of frequency quadrupled Nd: YAG laser for wire stripping [8]. Iceland has researched the usage of CO_2 and Nd:YAG lasers in wire-stripping equipment [9]. Miller has researched the ability of a 10.6 [μm] CO_2 laser to selectively remove the insulation of various materials [10].

The main purpose of this study is to determine the necessary parameters of a CO_2 laser system to completely remove the outer isolation layer of communication cables, deriving the functional dependencies of the depth of laser ablation on power, speed, the raster step distance and influence of material's colour on twisted pair CU cables outer insulation layer made of PVC with a thickness of up to 600 [μm].

II. INSULATION REMOVAL TECHNIQUES

The cable stripping process is the removal of the insulation, which covers the electrically conducting wire or wires of a cable, to make the cable-ready insertion in the cable connector. Conventional cable stripping technologies include abrasive, chemical, thermal, and mechanical methods. Each of those methods has its drawbacks in one or several areas such as damage to a copper conductor, low precision, quality, or poor processing speed.

In precise manufacturing applications where perfect insulation removal is needed it is unacceptable to have such deficiencies. Mechanical cable-stripping methods are not well suited to strip cables that do not have regular cross-sections like twisted pair cables, which are very frequently used in telecommunications. The quality of this process highly depends upon the skill and experience of the crafts-person to cut through the protective cover without damaging or stressing the elements [11]. Twisted pair cable (TPC) is composed of two conductors which are twisted together. The twisting is used to cancel electromagnetic interference from external sources and to reduce the cross-talk with surrounding wires (typically within large bundles) and it is also used to protect the environment from its radiation [12]. Chemical cable-stripping methods have a long processing time and environmental issues. Successful thermal cable-stripping requires very precise calibration and temperature control and it needs a secondary operation to completely remove all insulation from a selected area of the cable.

Laser cable stripping has a faster processing time, better process control, and very good precision compared to other methods. Laser cable stripping is a contact-less process and using appropriate laser type and laser power is important to significantly reduce the risk of damage to the copper conducting part. The laser beam can create a variety of patterns such as cross-cut end strips, angled cuts, mini-windows, or any programmable patterns and selected points of cable or wire. A list of insulation types strippable by CO_2 laser includes rubber, fabric, Teflon, polyvinyl chloride, Kapton, and fiberglass.

III. EQUIPMENT AND MATERIALS

ST-CC9060 laser systems were used in the experimental process for sample processing. Parameters of ST-CC9060 laser are shown in table I. This laser is specially designed for interaction with non-metallic materials. This system has and a high-speed XY coordinate table, with unique fully sealed cavity construction shown in Fig. 1.

Principle of operation: the resonator tube of the CO_2 laser is filled with a gas mixture as a laser-active medium. A laser discharge generates when high voltage is applied to the electrodes of the laser resonator, this process causes the molecules in the CO_2 gas mixture to release laser radiation in form of emissions. After amplification, in laser resonator photons leaves it through the output resonator. These photons, who are directional, monochromatic, and coherent from the laser beam with help of optical systems are directed to the work surface.

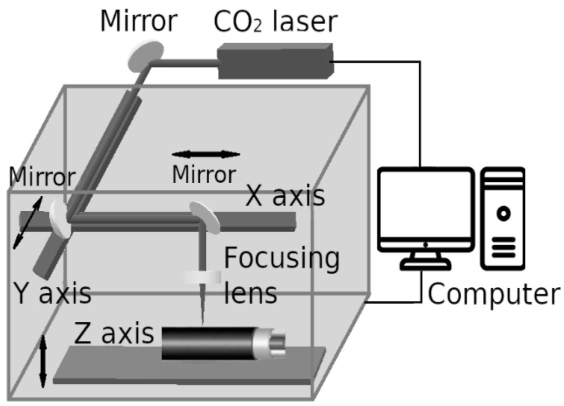

Fig. 1. Scheme of the operational stand

TABLE I. PARAMETERS OF ST-CC9060 LASER

Laser Power *P*	100W
Laser Wavelength λ	10640nm
Marking Area *S*	900 mm x 600 mm
Marking Speed *v*	0-1000mm/s
Repetition Accuracy	±0.02mm
Power Consumption	1.5 kW
Power Supply	220v/50Hz/10A
Cooling system	water cooling & protection system
Focal Length *f*	65 mm

For the parameter measurement of the heat-affected zone, an OLS-5000 SAF laser microscope (Fig. 2) was used. Magnification of 20x with repeatability – 0.03 [μm] was used for determining the width and depth of the heat-affected zone.

Fig. 2. OLS-5000 SAF confocal laser microscope

IV. MATERIALS / EXPERIMENTAL SAMPLES

PVC is a thermoplastic material, meaning that it can be softening when heated and hardening when cooled and it can undergo these processes many times without any noticeable change. Properties of PVC can vary depending on its molecular weight and additives (plasticizers, fillers, pigments, etc.) PVC is extremely cost-effective in comparison to other plastics with a high degree of versatility in end-use and processing possibilities. It is durable, easily maintained, and can be produced in a variety of colours. It has good stiffness, impact strength, good chemical resistance, and non-flammability [13, 14].

There are different types of PVC available on the market which can be used as an insulation material. The most common types are rigid PVC (PVC-U) and plasticized PVC (PVC-P) PVC-P is usually used for stranded cables where the flexibility of the cable is necessary. PVC-U is used for solid cables which are more useful for heavy-duty applications [13]. The most important parameters of PVC-P and PVC-U are shown in Table II. Another important factor that influences the absorbability of laser light for PVC is the colour of the material. colour or PVC depends on the amount and type of pigment additives present in the material.

TABLE II. PARAMETERS OF RIGID AND PLASTICISED PVC [13]

Property	**Rigid**	**Plasticized**
Density (g/m^3)	1.34-1.39	1.29-1.34
Tensile modulus (GPA)	2.41-2.45	-
Tensile strenght (MPa)	37.2-42.4	14-26
Density (g/m^3)	1.34-1.39	1.29-1.34
Elongation at break (%)	-	250-400
Notched izod (kJ/m)	0.74-1.12	-
Hardness	R107-R122 (Rockwell)	A71-A96 (Shore)

V. METHODOLOGY

Depth *h* of a single slit cut and 10 x 10 mm window cut area was measured as a function of laser power *P*, raster step distance Δx, and processing speed *v*. PVC-P strips of different colours (white, yellow, red, green, blue and black) with a size of 20 x 200 [mm], thickness - 0.6 [mm] were prepared for the experimental series. The focal length *f* and the spot size of laser beam *d* are constant throughout the entire experimental study – *d* = 92.7 [μm], *f* = 65 [mm]. Laser interaction time - *t* and laser power density – *W* were measured for all measurements. Error calculation was made for all measurements. Every experiment was repeated 4 times to achieve more reliable results. A 10 x10 [mm] window cut area of each sample was performed using a raster scanning method. (Figure 3.) Raster step distance Δx is the distance between the lines of the trajectory of the laser beam.

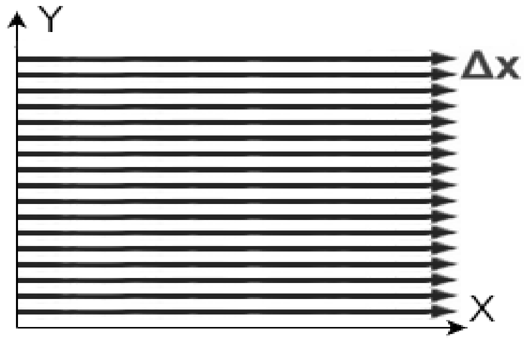

Fig. 3. Raster scanning method

Experimental part of the study is divided in four parts.

In the first section of the experimental process, ablation depth *h* was examined as a function of processing speed *v* - $h = h(v)$ for 10x10 [mm] area ablation for samples of six different colours. Values of *P* and *Δx* are constant through experimental series. *P* = const = 4.5, 7.3, 10.5, 14 W, *Δx* = *const* = 20 [μm]. *v* = 100 ÷ 345 [mm/s].

In the second section of the experimental process, ablation depth *h* was examined as a function of laser power *P* : *h = h (P)* for 10 x 10 [mm] area ablation for samples of six different colours. Values of laser power *P* used in these series: 1, 2.2, 3.5, 4.5, 6.1, 7.3, 9, 10 [W]. Values of *v* and *Δx* are constant through experimental series. *v* = const = 150, 225 and 300 [mm/s], *Δx* = *const* = 20 [μm].

In the third section of the experimental process, ablation depth *h* was examined as a function of laser power *P - h = h (P)* for a single-slit cut samples of six different colours. Values of laser power *P* used in these series: 1, 2.2, 3.5, 4.5, 6.1, 7.3, 9, 10, 12, 14, 17.6, 20, 23.6, 27.6, 30, 34.5, 38.5, 43 [W]. Values of *v* and *Δx* are constant through experimental series. *v* = const = 200 [mm/s].

In the fourth section of the experimental process, ablation depth *h* was examined as a function of raster distance *Δx: h = h (Δx).* Values of *P* and *v* are constant through experimental series. *P = const* = 4.5 [W], *v* = *const* = 100 [mm/s], *Δx* = 10 ÷ 80 [μm].

VI. Results of Experimental Studies

Results of the first set of experiments are shown in Fig. 4 and Fig. 5. Fig. 4 shows the depth of 10x10 [mm] laser-ablated zone as a function of the laser processing speed of four different colours – white, yellow, green, and black samples to make the graph clearer. Experiments where cable isolation was fully ablated (*h* > 600 [μm]) and the values of those measurements are not shown in Fig. 4.

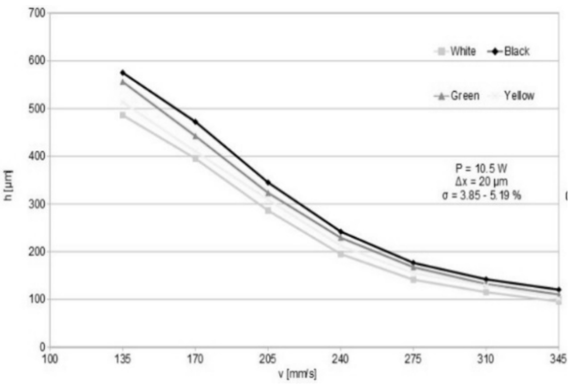

Fig. 4. Depth of the laser-ablated area as a function of laser processing speed

Data shown in Fig. 4 shows an increase of depth h of the laser-ablated zone by decreasing the laser processing speed. The trajectory of change of *h* is similar for samples of all colors, however, white-colored samples consistently are showing the lowest depth of laser-ablated area as black-colored samples have the deepest zone of ablation among experimental samples. Difference of *h* between black and white sample groups are between 15.4% at *v* = 135 mm/s and 20.5% at *v* = 345 mm/s. Fig. 5 shows how the depth of heat-affected zone *h* changes as a function of laser processing speed for four different values of laser power *P*.

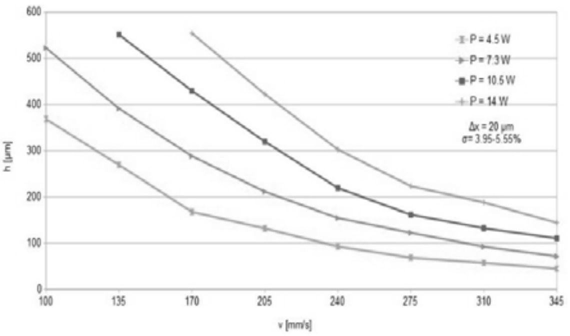

Fig. 5. Depth of the laser-ablated area as a function of laser processing speed of blue-coloured samples

A non-linear function can be observed. Changing laser power from 4.5 [W] to 14 [W] (311% increase) depth of laser-ablated zone at measured processing speed values where does not exceed (170 – 345 [mm/s]) increases by 320.9 – 330.6 %. Depth of the laser-ablated zone increases proportionally to increase the laser power.

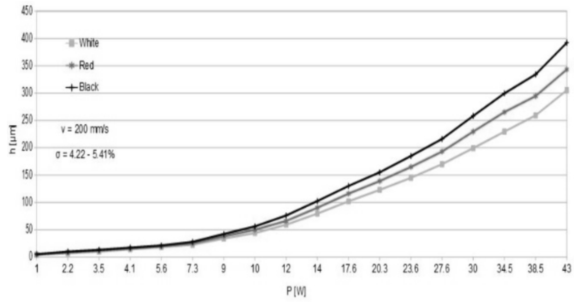

Fig. 6. Depth of the laser-ablated area as a function of laser power

Increasing laser power increases the depth of the laser-ablated zone exponentially as seen in Fig. 6. To analyze the way how increasing laser power *P* changes the depth of the laser-ablated zone, measured results were divided into four distinct intervals. Interval 1 – 1 to 10 [W]. Interval 2 – 10 to 20 [W]. Interval 3 – 20 to 30 [W] and interval 4 – 30 to 43 [W]. Increasing *P* of black-coloured sample in interval 1 - from 1 [W] (5.32 [μm]) to 10 [W] (56.13 [μm]) increases *h* by 1055%. This corresponds to a 5.65 [μm] increase in depth of the laser-ablated zone *h* per 1 [W]. Increasing *P* of the black-coloured sample in interval 2 - from 10 [W] (56.13 [μm]) to 20 [W] (155.09 [μm]) increases h by 176.3%. This corresponds to a 9.90 [μm] increase of *h* per 1 [W]. Increasing *P* of the black-coloured sample in interval 3 - 20 [W] (155.09 [μm]) to 30 [W] (258.36 [μm]) increases *h* by 66.6%. This corresponds to a 10.33 [μm] increase of *h* per 1 [W]. Increasing *P* of black-coloured samples in interval 4 - 30 [W] (258.36 [μm]) to 43 [W] (392.27 [μm]) increases *h* by 51.2%. This corresponds to a 10.30 [μm] increase of *h* per 1 [W].

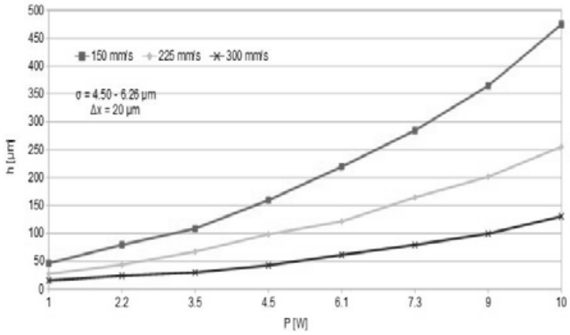

Fig. 7. Depth of the laser-ablated area as a function of laser power for three different processing speed values

Fig. 7 shows the dependence of 10 x10 [mm] laser-ablated zone on laser power *P* for three different laser processing speed values – 150, 225, and 300 [mm/s]. Results of red-coloured samples are shown in Figure 7 however a similar trajectory of change of *h* is noticeable for other tested colours, but the value of *h* slightly differs due to the absorbency of PVC plastic insulation for each colour. At P = 10 [W], v = 150 [mm/s], depth of laser-ablated area is 3.64 times larger than at P = 10 [W], v = 300 [mm/s].

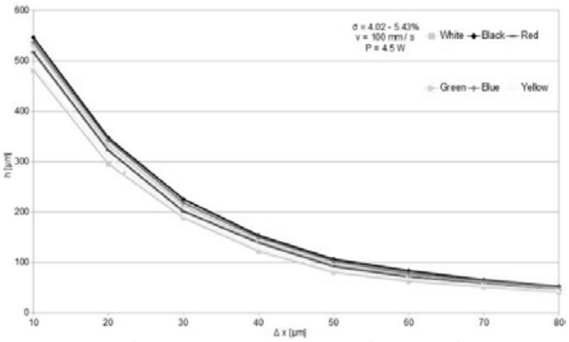

Fig. 8. Depth of the laser-ablated area as a function of raster step distance

Fig. 8 shows the dependence of the depth of laser-ablated area *h* on raster step distance Δx at v = 100 [mm/s] and P = 4.5 [W] for all 6 tested colours. Due to the beam diameter d = 92.7 [µm] and TEM_{00} laser beam, change of *h* between Δx = 70 [µm] and Δx = 80 [µm] is relatively small. As the value of Δx is decreased further, *h* increases exponentially.

VII. Summary

The following statements can be made from the analysis of the experiments:

- Using the selected methodology laser type and mode, it is possible to perform quick and effective ablation of commercially available telecommunication cable isolation. Laser power *P*, procession speed v, and raster step distance Δx (for area ablation) are the most important parameters in the ablation process of PVC for single slit cuts and 10 x 10 area ablation. [15, 16] The chemical composition of specific insulation material and its colour also considerably influence the ablation process.

- Experimental dependencies of these parameters and depth of laser-ablated area *h* can be used to properly adjust laser stripping of the cable insulation, depending on the thickness of the insulation layer and diameter of the cable core according to necessary safety standards, its functionality, and specific needs of a customer. These parameters can be changed at will to adjust to different insulation material, its colour, or thickness to make the process more efficient, for example, increasing processing speed v and laser power *P*, adjusting raster step distance Δx.

VIII. Conclusion:

Finding the optimal operating parameters for specific insulation material type and thickness and understanding how a change of parameters influences the geometry of the laser-ablated area are very important steps to achieve optimal laser-material interaction. Results of this study can be of interest to different industries, which manufacturing process include cables, wires, or other applications where it is necessary to remove an area of insulating material.

The present study examines the depth of the laser-ablated area as a function of parameters such as laser power *P*, laser processing speed v, raster step distance Δx as well as the influence of colour on the process of laser ablation on a PVC-P CU twisted pair cable outer layer isolation layer with a thickness of 600 [µm].

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