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SCWTEX – SIMULTANEOUS CUTTING AND WELDING OF TEXTILES

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ABSTRACT: *A combined cutting and joining process of technical textiles should help to reduce the number of production steps. Additionally, resources needed and waste should be minimized by a combined process. Process development is supported by Finite Element (FE)-simulations keep the number of experiments as low as possible. Ansys software has been chosen for process simulation and examples of polypropylene fibres cutting are presented. Depending on process characteristics one or two laser sources will be used for experiments. First experiments have been performed on polyamide, polyester and polypropylene woven and knitted fabrics. It is intended that energy consumption as well as resource-efficiency of the combined laser cutting and joining process will be optimized and compared to conventional processes. Increased efficiency simplified and reduced requirements on storage and logistics could be beneficial especially for small- and medium-sized enterprises (SME's) in Europe.*

KEYWORDS: *laser, textile, cutting, simulation*

INTRODUCTION

The main goal is the development of a process which combines cutting and welding of technical textiles by means of high power lasers. Although laser cutting is well established in cutting of technical textiles, laser welding of textiles is still in development. Nevertheless, welding of technical textiles allows the production of water-tight seams, which is important for functional clothing. Due to process characteristics, laser welding of textiles could be advantageous since no special tools are required. A combination of laser cutting and welding could be beneficial to reduce energy consumption as well as requirements on storage, logistics and waste management in the textile industry. In principle, one or two laser beams could be used for simultaneous laser cutting and welding. With a single laser beam the intensity at the centre of beam is chosen in such a way that the material is vaporized and the surrounding material is molten due to the reduced intensity of the beam and heat conduction. Unfortunately, due to the low heat conduction coefficient of synthetic materials heat flow is very limited which causes a steep thermal gradient within the textile and narrows the seam width.

With two independent laser sources, one beam could be used for cutting and the second beam could be used for welding. As an advantage, intensity, position and beam profile of two beams could be chosen independently. On the other hand complexity of the overall set-up, beam handling and shaping is increased.

MATERIALS

A careful selection of materials is of crucial importance for project progress. Main criteria were the suitability of materials for welding, as well as a certain use in the textile industry and ecological aspects. Since laser welding is a thermal process, thermoplastic behaviour is a basic requirement for weldability. As a consequence only thermoplastic synthetic fibres, fibres from the group of thermoplastic elastomers or fibres blended with such fibres as main components are considered. Process stability is facilitated by wide temperature interval between melting and vaporisation temperature of the chosen material.

Additives have also to be taken into consideration, since they can influence the behaviour of the material considerably. To reduce possible influences on results, sample materials with no, or at least as few as possible additives and finish have been chosen. Additionally, materials have been evaluated by means of their expected environmental impact during their whole live cycle. It is evident that the largest contribution to possible environmental hazards is related to pyrolysis of the particular polymer. In most cases, shielding gases can be used to decrease possible pyrolysis residues. With respect to an industrial application of the process, emissions caused by laser processing of materials have to be examined thoroughly. Additionally, possible contaminations of the laser treated textiles with toxic residues have to be judged in material selection. The following section gives a short overview about the selected materials:

Polyester (PES) - For first experiments, polyester has been chosens due to its vast number of applications in the textile industry. Besides its use in the clothing industry, polyester is used for agricultural-, medical or functional textiles. Thermo-physical properties of polyester are promising for the intended experiments: a deflection temperature of about 70°C, a melting temperature about 240°C and a vaporisation temperature higher than 300 °C (2).

Hazardous substances - *Most dangerous emissions during pyrolysis are p-creosols and benzenes (3).*

***Polyamide (PA)* -** *Polyamides are characterised by high strength, good abrasion- and bending strength. During production, mechanical properties can be adjusted to a wide extent (4). Similar to PES, applications are wide spread, ranging from clothing to technical uses.*

***Hazardous substances* -** *The major parts of emissions which appear during cutting with CO_2 Lasers are aerosols. They are mainly carbonyl compounds like formaldehyde and acetaldehyde (3). Formation of substances is caused by a radical oxidation of molecular oxygen, what indicates that these emissions can be decreased with an appropriate use of shielding gas.*

***Polypropylene (PP)* -** *Industrial use of PP fibres is very versatile. Besides classic applications, PP fibres are used in medical, technical and agricultural applications.*

***Hazardous substances* -** *The emissions which appear during pyrolysis of polypropylene can be explained by stochastic breaking of bonds between molecules, which results in the emission of n-Alkane, al-Olefins and al,om-diOlefins (3).*

EXPERIMENTAL SETUP

First orientating experiments have been performed with a single CO_2 laser beam and no additional measures to increase contact pressure. It is well known that the penetration depth of CO_2 laser radiation into synthetic materials is very limited (7). It was estimated that due to the finite thickness of the textiles used for experiments, a stable process can be achieved. Radiation in the wavelength range of Nd:YAG lasers shows almost no absorption without any additional measures. Evaluation of first results lead to the development of two-beam setup, see figure 1.

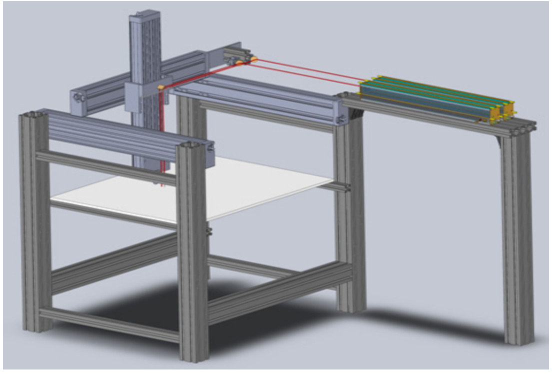

Figure 1 - Schematic view of a two beam experimental setup

Laser sources

First experiments have been done with two different CO_2 laser sources. Table 1 gives an overview of beam parameters.

Table 1 - Beam parameter EMCO LS140, Synrad L48-2.

	P max [W]	λ[μm]	d[mm]	Φ [mrad]
EMCO LS140	160	10,6	12	2
Synrad L48-2	25	10,6	3,5	4

P_{max} is the maximum optical Power, λ is the wavelength of the emitted radiation, d is the diameter of the raw beam, and Φ the full angle divergence of the beam.

Drawing device and sample support

To ensure a reliable thermal contact between textiles layers, a clamping device is required which is realized by means of a drawing roll, see figure 2. To influence the amount of heat flow into the drawing roll, a material with a low thermal conductivity e.g. ceramic and a second one with a higher thermal conductivity (steel) have been designed. Additionally, for well defined and constant dimensions of the welding zones such drawing rolls offer the possibility to influence the seam geometry. To ensure a constant contact pressure a compression spring with different spring pre-loads has been used. Preliminary experiments verified the assumption that heat flow into the support cannot be neglected. As a consequence, sample support has been changed accordingly.

Figure 2 - Different drawing rolls to ensure a well defined thermal contact between textiles. Steel (upper drawing) roll and ceramic roll

As already mentioned, shielding gas is needed to ensure a high quality of the produced seams. It inhibits or at least decreases the oxidation of the cutting edge, which decreases carbonation and emissions of hazardous substances. First experiments have shown that nitrogen inhibits at least carbonation significantly. But the use of shielding gas can also have a certain negative impact: Due to the gas flow a convective heat transfer occurs, which has a negative influence on the width of the weld seam. As a consequence, a careful control of gas flow is required.

Following first experiments, a two-laser setup has been designed and realised, where one laser beam is used for cutting and the second beam welding, see figure 3 and figure 4.

The lens can be tilted (0°-10°) around the axis in welding direction, which allow to chose a well defined distance between cutting and welding beam.

Table 2 - Parameter of the focusing element

Shape	Material	Diameter [mm]	Focal length [“]
Plan – convex	ZnSe	15	1.5

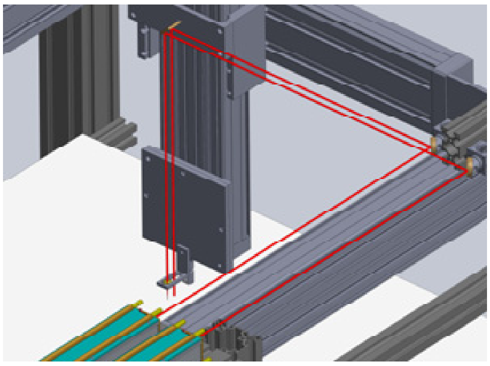

Figure 3 - optical path (schematically)

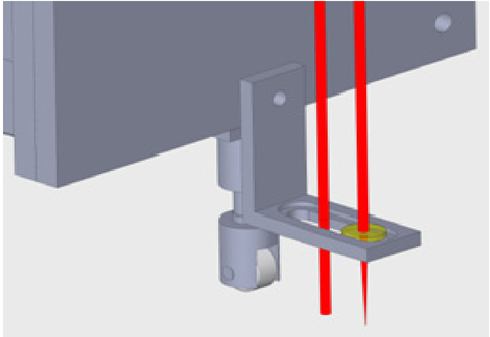

Figure 4 - detailed view of figure 3

EXPERIMENTAL RESULTS

First results indicate that with carefully chosen laser parameters cutting with almost no influence on the remaining material is possible with a simultaneous welding process. With a single laser beam used for first experiments it is clear that the interdependence of cutting and welding parameters restricts variations of parameters significantly, see figure 5 and figure 6.

Figure 5 - Laser welded sample, line energy 4.8 kJ/m

Figure 6 - back side of a laser welded fabric, line energy 4.8 kJ/m

As can be seen from figure 7 and figure 8, textile laser welding process is very sensitive against carbonation. During first experiments cutting respectively welding speed has been varied between 7 and 40 mm/sec, optical power between 10 and 50 Watt and spot size between 3 and 3.5 mm, specifications of textiles are shown in table 3.

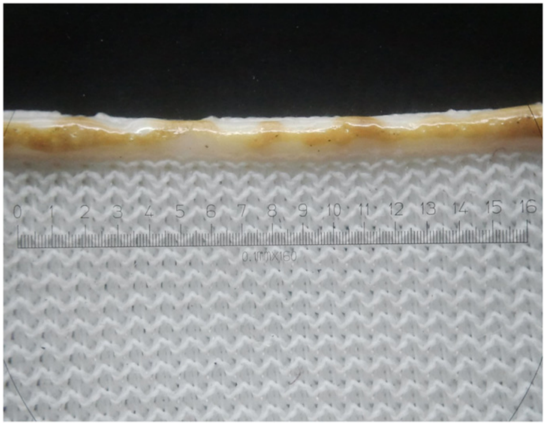

Figure 7 - Laser welded sample with carbonation of edges, line energy 4.1 kJ/m

Figure 8 - Laser welded sample with carbonation weld seam, line energy 4.1 kJ/m

Table 3 - specifications of textiles used for experiments and knitting machine

Textile parameters	
Course/cm	21.5
Wale/cm	14.4
Yarn count	50dtex f40
Machine type	HKS 3-E28
Machine stitch fineness	28 needles / inch

Due to the limited possibilities of the single beam option, additional experiments will be performed only with the two-beam setup. First results of the two-beam setup show a good reproducibility with results achieved so far. Nevertheless, efforts will be focused on beam homogenisation to achieve more precise control on weld behaviour.

FE-simulation

As already mentioned, the experimental part has been accompanied by FE-simulations to obtain a better understanding of the process as well as to reduce the number of experiments. A critical point in simulation of laser material processing is the implementation of a well defined heat source.

The mathematical apparatus is based on the solution of the Fourier-Kirchhoff's differential equation of heat conduction (Eq. 1) using the finite element (FE) method. Fourier-Kirchhoff's equation is shown below:

$$\rho . c(x,y,z,T)\frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\ \lambda_x(T)\frac{\partial T}{\partial x}\ + \frac{\partial}{\partial y}\ \lambda_y(T)\frac{\partial T}{\partial y}\ + \frac{\partial}{\partial z}\ \lambda_z(T)\frac{\partial T}{\partial z}\ + \dot{q}_v(x,y,z,t) \tag{1}$$

where: ρ - density [kg m^{-3}], c - specific heat [J kg^{-1} K^{-1}] T - temperature [K], t - time [s], λ - thermal conductivity [W m^{-1} K^{-1}], q_v - heat source [W m^{-3}]

It is well known that a precise heat input description is of crucial importance, especially including the laser beam cross-sectional energy density.

Following the literature, several heat source models can be applied. Within the model presented here, an approach as described by von Allmen (8) has been chosen. The laser beam used for simulation can be described by a by Gaussian distribution (Eq. 2):

$$q(x,y) = \frac{2(1-R)I}{\pi r^2} \cdot e^{(\frac{-2(x^2+y^2)}{r^2})}$$

where q is the energy density that reaches the substrate interface, I is the peak intensity of the incident laser light, R is the reflectance, and r is the radius of the beam spot. The incident beam irradiates the target surface at z = 0.

Von Allmen's model has been chosen since a user defined local coordinate system allows an easy re-calculation of the amount of heat input directly to the each irradiated element separately, regarding its x and y coordinate in the local coordinate system. The centre of this coordinate system is adjusted to the centre of the laser beam.

Moving of the local coordinate system as well as the irradiated elements selection and appropriate heat input, based on the distance from the beam centre was ensured by a user defined macro in the APDL (Ansys parametric design language) scripting language.

As mentioned earlier, the energy absorbed by elements significantly depends on the element surface position according the incoming laser beam center. Higher amount of energy near the laser beam center causes a more prominent rise of the element temperature and analogically a lower energy near the outer beam radius causes a lower element temperature. A certain amount of heat is conducted to neighboring elements. Since material properties are temperature dependent, material properties have to be adjusted accordingly. Additionally, phase transformation and thus specific heat of phase transformation have to be considered.

The elements temperatures have to be evaluated at the end of each solution substep. If the element temperature exceeds the defined ablation temperature, element becomes fully transparent for the incoming laser beam and its material properties are changed to the surrounding "air". The partial results showed, that no simplifications such as a 2D model or 3D model with axial symmetry are allowed, because a complex and spatially complicated problem has to be simulated. The scheme of the proposed solution is shown in figure 9.

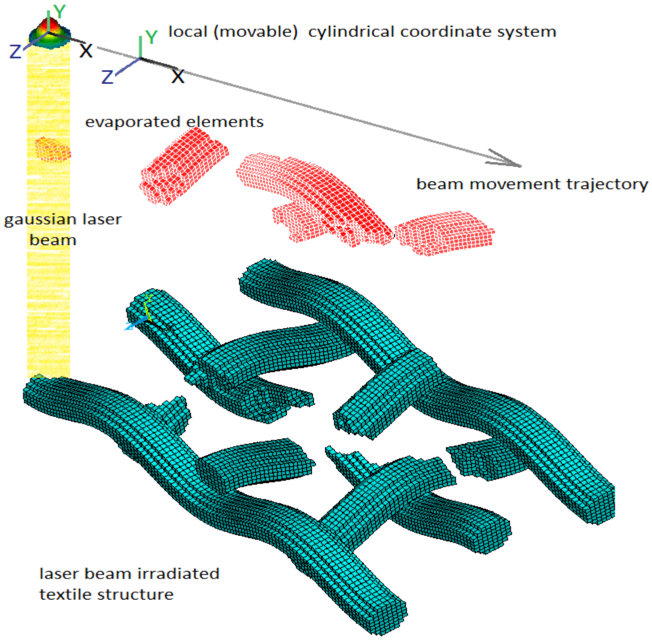

Figure 9 - Schematical view of model geometry used for FE-simulations.

Process parameters used for simulations are as follows: laser power = 50 W, beam radius 0.2 mm, polypropylene fibre radius 0.7 mm, velocity 1 m/s, absorption 95%, distance between the fibres 6 x fibre radius, evaporation limit 480 °C.

SIMULATION RESULTS

The proposed 3D model shows a promising way to predict the material removal by laser beams. The model provides full information about the cutting shape, the width of the cut and the molten area. Additionally, the model helps to get a better understanding on the physical phenomena involved in material processing.

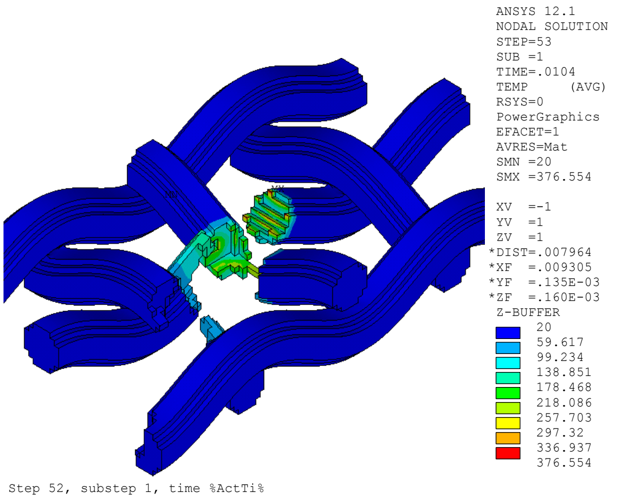

Figure 10 - Temperature field and cut shape. Simulation of polypropylene fiber cutting,; cutting velocity 1 m/s, step of the simulation 53; time 0.0104 sec

Model allows changing the geometry of the textile, material properties of the textile fibers very easily. Additionally, one of the most important benefits of the model consists from the possibility to keep full control over the laser beam – output power, energy distribution. Model even allows adding secondary beam or the change of the beam regime during the operation.

SUMMARY / CONCLUSIONS

First results indicate that a combined cutting and welding process of technical textiles seems possible. After implementation of a combined cutting and welding process in an industrial production environment, an overall increase of productivity could be expected. Especially requirements on storage and logistics as well as intermediate steps in production of technical textiles could be reduced by such a combined process. Nevertheless, additional efforts are required to overcome current limitations of the process. For industrial implementation there is also an extraction system for occurring by-product needed. These by products consist in this case manly in aerosols, formaldehyde, butadiene and acroleine.

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