Lasers in Manufacturing Conference 2015

Laser based surface structuring for lightweight design

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Abstract

One of the most important issues in automotive industry is lightweight design, especially since the CO_2 emission of new cars has to be reduced by 2020. Plastic and fiber reinforced plastics (e.g. CFRP and GFRP) receive besides new manufacturing methods and the employment of high-strength steels or non-ferrous metals increasing interest. Especially the combination of different materials such as metals and plastics to single components exhausts the entire potential on weight reduction. This article presents an approach based on short laser pulses to join such dissimilar materials in industrial applications.

Keywords: *lightweight design, short pulse lasers, surface structuring, micro processing, metal-plastic joining*

Introduction: Lightweight design in automotive industry

Since it is of importance for the daily life of most people, one of the most significant technological fields worldwide is automotion. Thus, it is not surprising that general global megatrends influence research and development in the automotive industry. One of the focus topics is the reduction of energy consumption and emissions in car manufacturing and, even more importantly, in car usage. The energy consumed by a vehicle over its lifetime exceeds the energy needed for manufacturing by far, which leads to a higher lever when aiming for reduced energy consumption of cars and trucks.

Besides the engine, there are four main factors driving energy consumption of a running car: The degree of efficiency of the car's axles, rolling and air resistance, and vehicle weight. A relative improvement of these four influence factors result in different levels of reduced fuel consumption. Naturally, reducing vehicle weight results in a significant decrease in energy consumption. Therefore, it has been a focus of many automobile manufacturers to reduce the weight to the highest possible degree. However, modern cars and trucks are very well engineered and most of the low hanging fruit in reducing weight have already been harvested. Therefore, designing and manufacturing lighter vehicles is a huge challenge: it is not enough to simply leave something out or to make parts smaller – cars have to be consequently re-designed and new materials and new manufacturing processes have to be employed.

Recently, the automotive industry started to increase the amount of light weight materials in car bodies. Magnesium and aluminium are no longer considered exotic materials reserved for sports cars but have found their way into serial production. Additionally, new steels have been developed that allow for dramatically increased strength. So called press hardened steel is heated to over 900°C before being formed in water cooled tools. Thus while forming, it is cooled rapidly which leads to changes in the crystal structures and therefore to the desired high strength and stiffness. Weight reduction is then achieved by decreasing sheet thickness or number of parts in structural car body assemblies. The hardness of press hardened steel is so high that mechanical post-processing is not feasible and final shape cutting of parts has to be done by laser.

Carbon fiber reinforced plastics (CFRP) have been used frequently in motorsports and aeronautics but are now also used in mass production (e.g. BMW i3). Besides CFRP, high quality plastics also find their way into structural car parts. By substituting metal parts and using hybrid metal-plastic construction, vehicle weight can still be reduced further. For both, fiber and non-fiber plastics, however, industrial processing at low costs per part is challenging. Especially joining plastics to metals without additional elements like screws or rivets is a difficult task. We believe that the laser based process we suggest in the paper at hand can fulfill the high requirements of automotive manufacturing.

LASER based approach for metal and plastics joining

There are different existing conventional approaches to join plastics and metals. The most commons are as mentioned screwing, clamping and riveting. All these methods require additional pieces and material, such as nuts and screws. Hence these conventional methods are not capable for light weight design since this additional material effort leads to an increasing amount of mass.

A different approach is gluing. Here additional pieces and their masses are avoided. This method, however lack the necessary strength, which is correlated to the stability and thus the safety of the entire construction, which is especially of relevance for human transportation. The correlation of weight on the one hand side and stability and thus safety on the other hand side is a fundamental limitation for light weight design.

In order to overcome this conventional barrier of the mentioned techniques TRUMPF developed a laser based approach in order to join metals and plastics with force and tight fit. In a first step the surface of the metal is structured by laser irradiation to form large roughness with undercuts. As laser source a short pulsed laser system with high average power is necessary. Single pulses allow applying spots of laser pulses along the axis of the feed rate with a well defined overlap. Hence pulsed lasers are capable to apply non-homogeneous ablation along both axes of the surface. Furthermore for applying a fine surface structure short laser pulses in ns-range enable to achieve extremely high peak powers in order to ablate material only in a well defined area. The economic feasibility however is ensured by a laser system with high average power.

In a second step the still heated structured metal surface is pressed together with the plastic part. A Diode laser, in continuous wave mode, heats the thermoplastic part from the back side beyond the glass transition temperature. By pressing the two parts together the plastic materials flows into the undercuts of the metal surface, forming a tight fit upon cooling. The process is schematically shown in Figure 1.

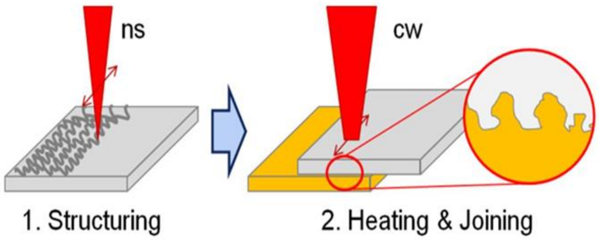


Figure 1: Principle of the joining process. A metal surface is structured with a nanosecond laser to form a big roughness and undercuts. The thermoplastic part is heated by a cw Diode laser. Melt of a thermoplastic part can flow into the structures to form a durable connection.

Alternatively the heating can also be performed by induction. In this method the thermal energy is transferred to the plastic part by the metal.

For testing the laser based approach we used the laser systems TruMicro 7060 and TruMicro 7240. These lasers are disk amplified short pulsed laser system for industrial application. The pulse duration was in ns regime and the wavelengths were 1030 nm and 515 nm respectively (for full specs see Table in figure 4). For scanning the joining area of the metal part a galvanometer scanner was used. These scans were performed by varying speeds and scanning geometries. As process gas nitrogen and compressed air have been applied.

Results

In our experiments, we were able to join steel and aluminum with several plastics. Figure 2 shows typical good results with a high density of irregular surface structuring containing undercuts. The quality of the joint depends on the size as well as the form of the structures. Hence the structuring parameters have the biggest influence on the quality.

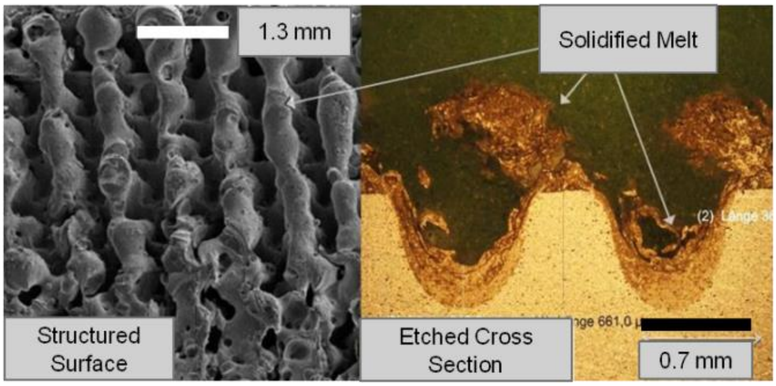
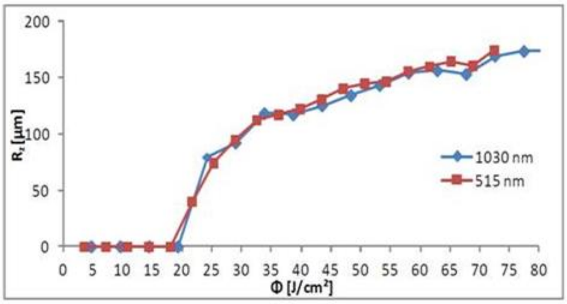
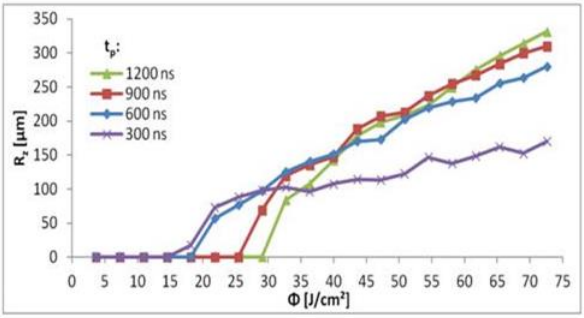


Figure 2: Microphotograph and etched cross section of a structured steel sheet

The strength of the joint depends strongly on the structure density, the overlapping area, as well as the depth of the structures. Thus the experimental parameters of interest for the joint quality are pulse energy, focal spot size and scanning speed. However we did not see a dependence of the wavelength. The measured structuring depths as function of the applied fluence for the wavelengths 1030 nm and 515 nm, while all other parameters were chosen to be equal, are shown in Figure 5 (left side). The dependence of the structuring depth on the pulse duration as function of the fluence is shown in Figure 3 (right side). Shorter pulse durations enable lower ablation thresholds but decrease the structuring depth per pulse.



Laser	t_p [ns]	f_{rep} [kHz]	d_f [µm]	P_L [W]	E_p [mJ]	max. I [MW/cm²]	max. F [J/cm²]	n	z [mm]	v_s [m/s]	U [%]
TM7240	600	40	100	var.	var.	121	72,6	1	0	0,4	90
TM7050LP	600	40	100	var.	var.	136,7	82,1	1	+	0,4	90



Laser	t_p [ns]	f_{rep} [kHz]	d_f [µm]	P_L [W]	E_p [mJ]	I [MW/cm²]	F [J/cm²]	n	z [mm]	v_s [m/s]	Ü [%]
TM7240	var.	40	100	var	var.	var.	var.	1	0	0,4	90

Figure 3: Left side: Structuring depth R_Z as function of the fluence for the wavelengths 1030 nm (laser: TruMicro 7050 LP) and 515 nm (laser TruMicro 7240) as well as the applied laser parameters. Right side: Structuring depth R_Z as function of the fluence for several pulse durations t_P as well as the applied laser parameters. F_{rep}: repetition rate, U: spot overlap, v_S: feed rate, t_P: pulse duration.

As shown in Figure 4, the highest joint strength was achieved at structure depth of 300 µm, measured from the original surface to the structure ground. Structure depths beyond 300 µm do not increase the joint strength since the tensile strength as function of the structure depth shows a saturation effect for higher structure depths.

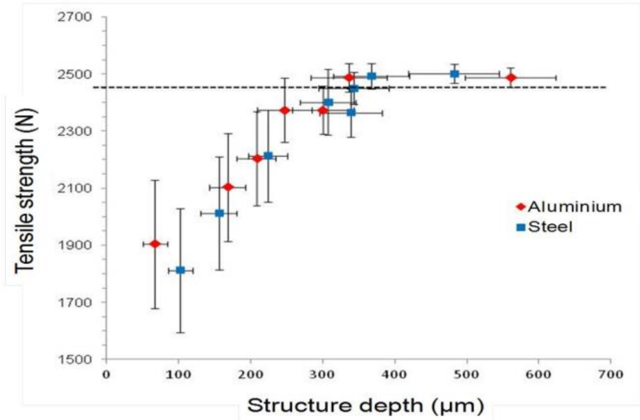


Figure 4: Tensile strength of aluminium / steel joints as function of surface structure depth.

For structuring steel, nitrogen as a shielding gas is necessary in order to prevent the surface from oxidation and corresponding impairment of the surface quality. For aluminium however, no processing gas is necessary. For choosing optimal laser parameters, the results for structuring steel and aluminium are very similar. For both metals and various thermoplastics high strength connections can be achieved.

While for a steel plastic connection, the plastic is the weaker material in the joining zone, in case of the aluminium-plastic the connection can break in both materials. Since thus the overall strength of the aluminium-plastic connection is limited, the strength of the steel-plastic joint is higher. Further the steel-plastic joint allows to does the heating via heat conduction. Hence the process could also be performed to join fiber reinforced plastics with high strength. For structuring steel, an intensity of 7 MW/cm^2 is needed. For aluminium however the necessary intensity of 30 MW/cm^2 is even higher.

Conclusion

Laser technology provides three major advantages: Lasers are an efficient tool which stands out due its high energy conversion rats, laser technology is a key for efficient production processes and further lasers pave the way towards efficient products such as lightweight cars. The potential and possibilities of this technology are still not yet exhausted and novel manufacturing methods can be engineered.

Incorporating (fiber reinforced) plastics into metal pieces and constructions can lead to novel designs for lightweight design. We developed a promising surface structuring approach based on mano-second laser technology to enable the joint of such very different materials like metals and plastics.

The joining method presented in this article is very straight-forward and combines high quality connections and good tensile strength. It does not need additional supplementary material. This saves weight, costs and complexity. Further, the process can easily be automated and employed in mass production.

Acknowledgements

The presented process was developed within the research initiative *"Extralight – Extremer Leichtbau mit Kunststoff-Metall-Hybriden"*, by the Federal Ministry of Education and Research (BMBF) of Germany. We thank the BMBF and all involved project partners: Albis, Allod, BASF, TU Berlin, Daimler, INPRO, Neue Materialien, Thyssen Krupp, Volkswagen.