IN MOULD LASER WELDING FOR HIGH PRECISION POLYMER BASED OPTICAL COMPONENTS

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Abstract - Assembling a complete subsystem as a rear lamp, it is necessary several different machines and tasks, for producing the final product. The technology presented in this paper has de capability to reduce the number of tasks needed for producing a final subsystem/product. In this case will be necessary only one injection moulding machine with three injection units. This was achieved by combining several technologies, as in-mould assembling, laser welding and LEDs.

The challenges began by studying several polymeric materials, for understanding their behavior when they are welded by a laser beam. This was helpful also for determine the best welding properties. At the same time were analyzed different conductive polymers. This had the objective to determine their suitability for conducting the electric current between the different LEDs. The development of the rear lamp was made take in consideration the legislation of UNECE Vehicle Regulations - 1958 Agreement; Regulation No. 50 -Rev.2 - Position lamps, stop lamps, direction indicators for motorcycles. The results obtained present good input for producing in the same machine a complete and functional rear lamp.

Keywords: Laser, transmittance, polymer, conductive, LED, seams, mold.

Introduction

Along last years, welding laser technology is being improve and growing in a very competitive market, where it is possible to find innumerous solutions for parts assembling, from glue solutions to complex processes as ultrasonic welding process. This market increment is achieved by the versatility that this type of technology is capable, mainly because the linkage between the laser head and the robot. It is possible to weld almost whole plastic parts that exist on the market. The major exception is to weld different materials with a melting temperature difference of 50ºC. [1]

With this technology is possible to find two possible processes, the direct and by transmission. The first process is use mainly in metals or in plastic films. [2] In this case the two materials are in parallel and connected and both absorb at the same time whole the energy. The second process is the most used in plastic industry, mainly because of the major parts of plastic are transparent to the laser beam (600 to 1180 nm). To overcome this difficulty is common to use additives as black carbon, lumogen or clearweld, to improve the absorption by the material. The transmission welding is a very simple process. Two materials, one transparent to the laser beam and other with the capability of absorbing the laser, are in contact by pressure and then the laser makes the seam. Welding by transmission it is presented in the figure 1.

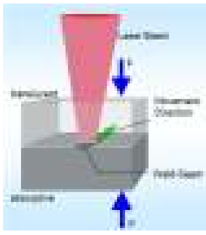

Figure 1 welding by transmission [1]

Beside the laser technology, in this project was the objective of applying LEDs (light-emitting diode) and conductive polymers to the motorcycle tail light. The application of these two solutions will help to decrease the electric consumption of the lamp and also to improve the flexibility of the design.

In the last years the mould making companies, developed enormous varieties of mould solutions to improve the production cycles by decreasing the parts assembling and post operations outside the mould.

Base on the research made the most innovative techniques are mould with multiple partition lines or rotating plates with the capability of changing their configuration during the injection process. Another common process is the utilization of robots or similar solutions for doing the exchange of the different parts between different cavities or machines.

With the technique shown in this paper it is possible, to produce the final parts in one mould. The In-mold assembly assures the exact alignment of the different components of the final product.

The process reduces the total time of production and assembling.

Results and Discussion

The work presented in this paper has the objective of presenting all the steps needed to make possible the combination of different technologies as laser welding and in-mold assembling, in producing in a single process a complete an functional motorcycle tail light,. The case study chosen is constituted by three parts a black part named housing made in PC with the color black, an incandescent light bulb, and a lens made in PMMA. The actual tail light it is presented on the figure 2

Figure 2 actual tail light.

The first step made was the laser transmission analysis. This was made in a spectrophotometer Shimadzu UV-3101PC UV-VIS-NIR. NIR spectroscopy study was between the two amorphous materials, in this case the PC and PMMA. The main objective was to analyze the influence these materials on the transmission of the light. The results for the two amorphous materials analyzed showed high transparence in all NIR spectra. With this results, can be concluded that these two materials can't work as absorbent materials. The only difference between them happens when is emitted the wave with wavelength of 1150 nm. In this spectrum the transmittance of the PC is less than PMMA. Take in consideration that these two materials have a different molecular chain, was expected different behavior which didn't happen. This shows that for polymers amorphous materials the molecular chain will not affect the passage of the laser beam. The comparison between the PMMA and PC it is presented on the figure 3.

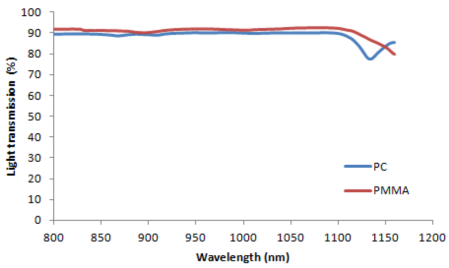

Figure 3 PMMA spectroscopy

Base on the NIR analysis, the following step consisted on seam mechanical resistance. For these test were injected plates of the materials previous analyzed. The seam resistance was made according with norm EN 12814-3.

The procedure used on this study was taken into consideration the welding path of the rear lamp. The materials tested on NIR analysis. The welding velocities were assumed. The laser power was determined by a pre-welding analysis.

On these study were used the following values;

- Velocity: maxima: 40 cm/min, minima 20 cm/min
- Diameter: maximun 2 mm, minimun 1 mm
- Power: maxima 40 Watts, mínima 20 Watts

In this first mechanical tests was decided the use of the materials that are already present on the actual tail light. In this case was used the PC as the material absorber (housing) and PMMA as transparent to the laser beam (crystal). They were chosen, since these materials have an high impact resistance and can be welded, because their glass transition temperature (Tg) is very closed. Other positive factor it is the higher transparency of the PMMA compared to the PP. The high transparency to the laser will reduce the power needed to weld these materials. Take in consideration that PMMA is an amorphous material, the LEDs light intensity will not be reduced along the lamp life, increase with this the safety of motorcycle driver.

In the following table 1 it is present the Taguchi L8 table, used on the tests for welding the PMMA (transparent) with PC (absorbent).

Table 1 Taguchi L8 for welding the PC with PMMA

	Laser Diameter	Laser Velocity	Laser Power	Number of specimens
E1	1	1	1	4
E2	1	1	2	4
E3	1	2	1	4
E4	1	2	2	4
E5	2	1	1	4
E6	2	1	2	4
E7	2	2	1	4
E8	2	2	2	4

For testing the different specimens welded at the different conditions was decided to use the norm EN 12814-3, testing of welded joints of thermoplastics semi-finished products- Part 3: Tensile creep test. This norm does the regulation of the nominal dimensions according with the nominal thickness of the specimens. The specimens tested, had a nominal thickness of 2 mm, which gave a final thickness of 4 mm.

The next tests were the mechanical tests, using for that a universal test machine Instron 4505, with a displacement velocity of 1 mm/s

The first mechanical tests to be presented were made between the different specimens of PC/PMMA. These tests were made at the temperature of 23ºC. In the following paragraphs will be present and discuss the results of the tests in terms of the maximum load and maximum deformation.

The PMMA present a high transparency when a laser beam crosses the material. This behavior had an important influence on the uniformity seam resistance.

This uniformity was verified in the joining analyzed, despite of being measured temperatures of 700ºC. These temperatures were obtained, when the power of 40W was applied. It is necessary take in to consideration that this temperature was measured on the edge of the specimens and was independent of the velocity used. Was also saw smoke on the transition zone (edge of the specimens), when this power his applied. The smoke observed during the welding, was later confirmed that was released by the absorber materials. The evaporation of the material has created zones of weakness on the final seam. Despite the visual analysis had showed specimens with a good seam, the mechanical tests showed the contrary. Some specimens when fixed to the clamps of the tensile machine, the seams crack without making any force. Despite of this problem, was possible to teste at least three specimens of which welding conditions. Considering the results obtained, it is possible to concluded that the specimens welded with the lowest laser power, lowest velocity and lowest diameter present higher resistance to the load applied. The others specimen welded with the other conditions present a lower resistance. In this case they present a resistance in average below 100 N compared to the specimens welded with the conditions 1.

The results for the force of the eight different conditions are presented on the figure 4. Comparing the different standard deviation of the all specimens welded with the different condition, was possible to conclude that were the conditions E4 and E5 that present the smallest deviation. The welding condition E1 promote a higher seam resistance despite of presenting a higher standard deviation compared to the condition E4 and E5.

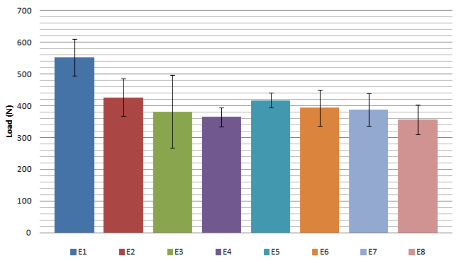

Figure 4 Resistance of the welded PC/PMMA

The final test was the visual inspections that were made using a Lupe Stereoscopic Nikon SMZ-10 and the digital camera Olympus DP11 with an augmentation of 4 times. Take in consideration the augmentation used and the width of seam, was not possible take a photo of whole seam. For this reason were presented two photos of each welding condition. One of the photos it is on the middle and other on the edge of the seam. In this case the photo on the left is in the middle of the seam and the right on the edge.

First will be discussed the seam quality on the welding made PMMA/PC. The photo taken on the middle, presented a small mixture between the two materials (inside of blue circle). Was expected a continuous mixture of the two, along whole the seam. This result could be explained by a low pressure applied to these materials. At the same time the image show a perfect contact between the two materials and is not possible to see any void. The only feasible explanation comes from the low thermal heat conduction between the two materials. In this case the material that's absorbs the laser didn't conduct the necessary heat to the transparent part.

The photo taken near the edge of these two materials welded has showed a gap (inside of blue circle). The one explanation comes from low pressure applied into the edge of two plates. This means that is necessary to increase the pressure only in the edge to keep the two parts together. This gap will create a weak point, when similar specimens welded with these conditions are under a constant load. This means that the propagation of the crack will start from this point. The brittle gray material presented on the photo is burn material. In figure 5 are presented the photos taken on the welding zone PMMA/PC.

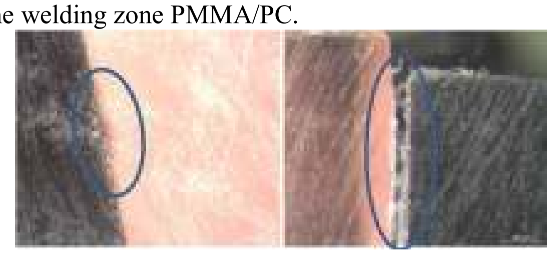

Figure 5 Seam of the weld between PMMA with PC

The next step was applying the LED technology and conductive materials to the tail light in study. After a market analysis was chosen use the HPWT-MD00-F4000 LED of Lumileds Lighting U.S. and a mixture of PC with 5% carbon nanotubs. main reason for choosing that type of LED was the high luminous flux output, in the case of conductive material the main reason was the low resistivity in this case <10 ohm.cm. After injected with the conditions given by the supplier of the raw material was possible obtained all the leds on. [6-9] The result is presented on the following figure.

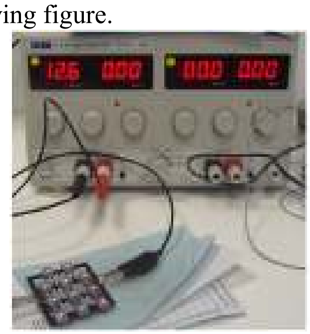

Figure 6 electric circuit

The Application of these two new applications, need to obey to the legislation in this case to UNECE Vehicle Regulations - 1958 Agreement; Regulation No. 50 - Rev.2 - Position lamps, stop lamps, direction indicators for motor cycles. According with this law the tail light need to be visible according with angles show in the figure 8 and 9 and luminous intensity of 4 to 12 candela to the rear position light and 40 candela to 185 candela to the stop light. [4] [5]

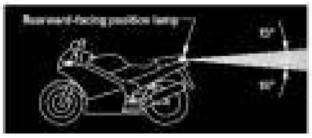

Figure 7 vertical visibility angles [4]

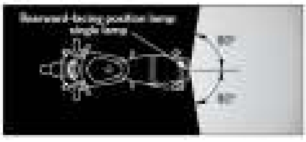

Figure 8 horizontal visibility angles [4]

Always taking the legislation present on the development of the rear light was realized that LED only doesn't accomplish these requirements. For that reason was necessary applying some concept of lighting, in this case the secondary optics, like pillow lens and reflector cavities.

Applying the conductive materials and secondary optics was achieving the following design, presented in the figure 10.

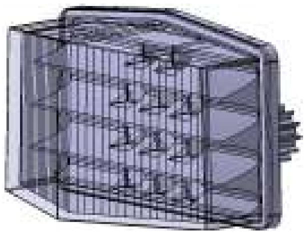

Figure 9 the new tail light

It's important state that the all process will be made inside of the same mold. For achieve this requirement of the project, was decided to use rotary plates, as it's shown in the following figure11.

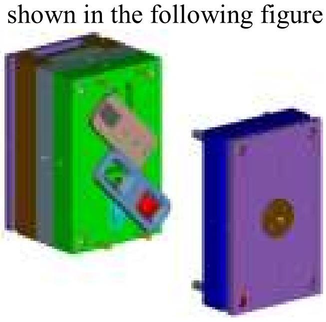

Figure 10 mould concept

Conclusions

From the results obtained I this study we can conclude that:

The utilization of LEDs force the utilization of structures as pillow lens and reflection cavities to overcome the legislation requirements.

Two electric conductive additives were tested. The additive that gave the best results was the carbon nanotubs (CNT). The results showed also that for this application the best material is the mixture of 5% or CNT with PC. The mixture of glass fibers in the polymers decreases the transparency of these materials to the laser beam. The amorphous materials presented low standard deviation and a good more seam resistance.

The best welding properties achieved were done at the lowest laser velocity, the lowest laser diameter and lowest power.

Acknowledgements

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