EMISSION OF SPATTER AND DROPLET IN A SHIELDING COMPONENT USED ON LASER WELDING CELLS FOR AUTOMOTIVE ASSEMBLY

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***Abstract**: This article aims the evaluation of a protective window, which is part of a LASER welding system. This component is used in automotive body-in-white (BIW) LASER welding processes to protect other high value optic components against weld spatters, metallic vapors and smoke. The referring concern to optimize its use is related to the fact of being a component whose continuous substitution in some levels of work volume brings high costs to the process. If its replacement, by means of one proposed index of degradation will not be well defined, will cause breaks in the process flow, either causing demerit to the product quality or increasing the final cost of the product because of its excessively replacements. However, even though the constant increase of the employment of such a componen, its production on a large scale with supply for multiple manufacturers is still a distant fact. It continues being made for few specialized companies around the world hindering a significant reduction on the unitary cost. The importance of this article becomes evident in this case because it not only demonstrates the viability in the reusing of the protective windows, but also defines a way to determine the maximization for using such component without affect the final product quality.*
Key-words: Nd-YAG, coated steel sheet, laser, welding, spatter, droplet

1. INTRODUCTION

In the automobile industry, specifically in body-shop area, responsible for the geometry and structure of a vehicle, the LASER weld technology has being employed to reduce the amount of weld-resistance points using LASER welding processes strategically located. Weld-resistance devices cannot make these welding, most of the time, once they have dimensions that do not allow them to reach certain difficult regions (Figure 1). Another advantage of using LASER in weld processes is the possibility to drastically reduce the steel sheet deformation that occurs with high thermal gradients found in the region affected by the heat (Figure 2) through this process once it is possible to obtain high densities of power with a LASER beam. Finally, using this type of LASER it is possible to deliver the LASER beam to the process through flexible and dedicated optical fiber, which contributes for the easy access to difficult regions of the body-in-white through robots manipulation. The installation used in this study is a body shop geometry station composed by two LASER weld cabins. One of them for VW-Polo Hatch-back and Sedan models and another one for VW-Fox model. Both cabins are supplied by LASER, which is generated in seven different generators with six exit channels in each one. These channels distribute LASER beams through the optic fiber to the optical heads, which focus the LASER beam in the process. The LASER is used for weld accomplishment of two distinct forms. The first one is the weld process for steel lap-joint union, where two or three sheets are mechanically joined and receive a perpendicular LASER beam to concatenate them by fusion. The second one is the brazing process, only applied in the region where roof and side parts are joined by their borders using a $CuSi_3$.

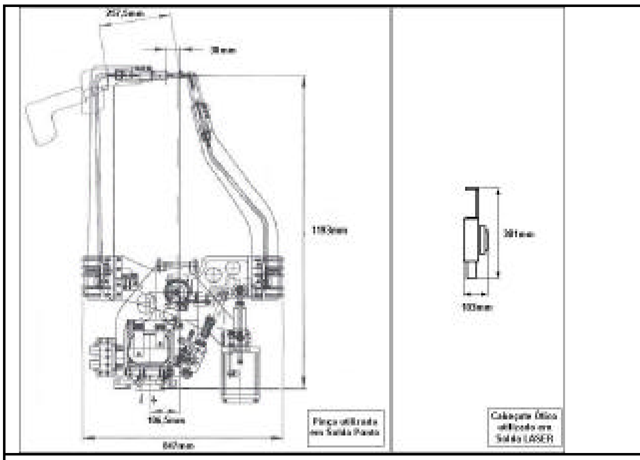

Fig. 1 Dimensional comparison between a ERSW clamp and a LASER optic head.

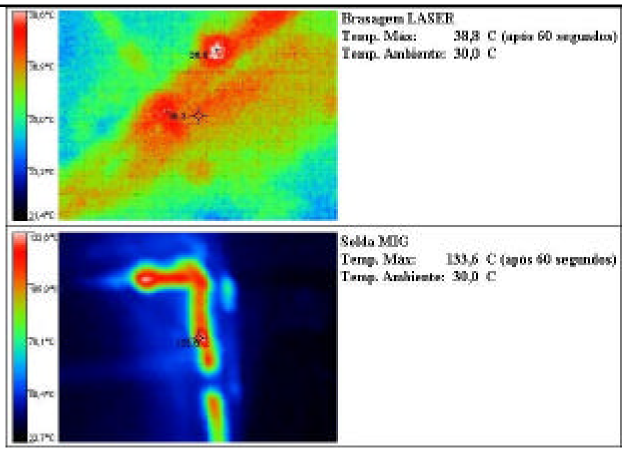

Figure 02 - Thermal comparison between MIG welding process and LASER welding process.

It is very important to stand out that initially only the first thin surface layers absorb the radiation. In metals, for example, whose initial absorption coefficients are around 2%, the beam energy is only deposited on fractions of microns of the steel sheet. Concerning this fact, the material emissivity is more important just in the first instants of the radiation and metal interaction, and it doesn't have an important function in the phase of the formation of the fusing puddle. Great amounts of the zinc element are evaporated from the fusion bath and can produce irregularities in the welding processes, as well as spatter. Frequently, a brazing with porous structure is caused by the early release of the zinc vapor among the fused metal puddle and is easily observed (in our study a league of copper and silicon is used).

2. SPATTER: A THERMODYNAMIC DISTURB

The pressure of the vapor in the puddle raises the fusing metal. The metal has a trend of being kept in the fusing puddle due to a combination of the gravity force, viscosity and superficial tension. In the melting puddle interior, the high gradients of temperature and pressure transmit dynamic energy of high degree to the flowed substance, followed by its particular thermal transferences. When the amount of energy in the fusing puddle reaches energy levels enough to expel substance, it will generate spatter and consequently degradation of the protective windows. The results of these high temperature gradients are the reactions of excitement and ionization of vapor atoms whose latent heat are bigger than those which occur on the phase changes in the welding zones using generic welding processes. For the LASER weld process, the combination of the superficial tensions balance of the melting puddle with the intense variations of temperature in a very small distance, causes the formation of a narrow and thin weld cord, or in other words, with depth and width narrowly related. It possesses the additional advantage of limiting the heat affected zone (HAZ). On the other hand, the speed of these reactions, associated with high cooling gradients, generates new structures formed by microstructures with homogeneous and extremely thin grains, which contend few impurities in the metallographic plan. In these welding processes, the mechanical properties as hardness and resistance to the tension are comparable to the ones of metals before the welding.

It is important to keep in mind that most of the spatter problem comes from the substances that take part in the process. This information proceeds from the experience acquired after some years of work with LASER geometry stations. In second place the sub item variation in the fixture system is noticed. From the moment when the installations and equipment of a LASER weld system are correctly maintained, with an adequate maintenance program and directed to use and take care of manufacturers specifications and recommendations, it can be said that the equipment in its totality does not suffer with great variations that are capable sometimes to impose to the system temporary increments of spatter. This fact occurs because of the random dimensional variations in the product, which causes material deviation in relation to the focal, leading it out of a stable work point of the LASER beam. Consequently, it moves the conditions with which the thermodynamic process expels the substance from the fusing puddle. Either the contamination of parts with oil coming from the press shop area or the contamination by adhesives used in body shop area can influence in the increase of the number of spatter and in the increase of the colloidal dispersion that also is a serious agent of contamination that intervenes directly with the lifetime of protective windows. The main optical parts of an adaptive LASER optic head for beam application are the collimation and re-focalization lenses and also the protective window (Figure 03). The function of the protective window, which is the last optic component of the adaptive LASER optic head and the object of study in this article, is to protect the focalization lens against dust, smoke and spatter during the weld process. A blower, distant approximately 50mm of the focal point, is responsible to generate a compressed air curtain which purpose is to reduce or forbid that weld spatter be deposited on the surface of the protective windows.

The effect of the spatter deposits on the protective window surfaces causes troubles to the LASER beam (Figure 4) because in these areas where the beam founds a barrier, the LASER is absorbed, generating accumulation of heat in high temperatures. The absorption process promotes an acceleration of the degradation of this component. Consequently, it increases the risk of damages to the focalization lens. Moreover, the radiation is reflected to the generation system in form of diffuse light. The degradation standards are very diverse, as it can be seen in Figure 5.

Considering a steady process, the variables that manipulates directly the speed of degradation of the protective windows are many, with highlights to the positioning and angle of work of the adaptive LASER optic head, the amount of weld carried through, the pressure of compressed air used in the protection curtain, the LASER power used and the amount of impurities on the steal sheet. The variables that were not considered in this list are: distance between adaptive LASER optic head and product and focal distance once they remain constant throughout the process and do not have changes in none of the levels of application of the LASER beam.

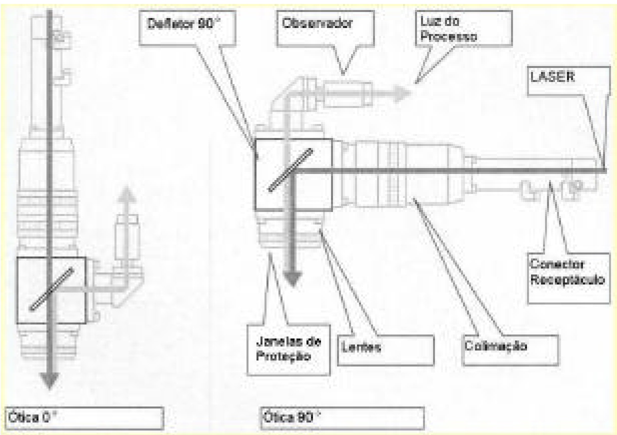

Figure 03 – Adaptive LASER optic head.

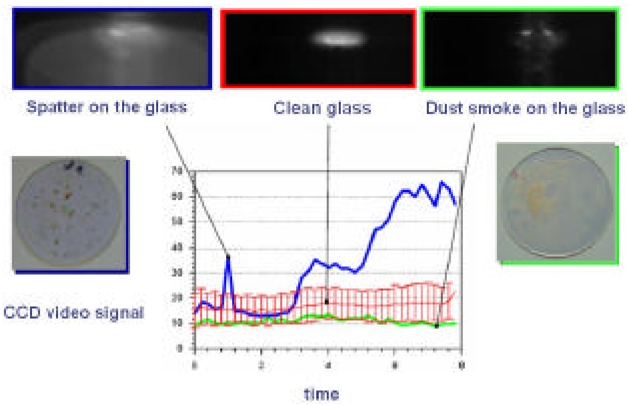

Figure 4 - Analysis of a LASER beam behavior using a CCD camera in 3 different conditions . Apud Hoffman 2003.

Considering spatter deposition on other optical components, it is important to keep in mind that its increasing accumulation leads to other problems like the blockage of the blower output and help to prevent spatter deposition on protective windows surfaces. There is none automatic cleaning system for the protective windows, thus causes continuous production breaks along one day. Still considering the idea of an automatic cleaning system for the protective windows, even if the spatter could be removed from its surface, we would still have to face the challenge of removing it without removing the original protective coating on its surface. Without this coating, the protective window is useless. The protective windows used in the LASER welding processes at medium power of 4000W are components made of Quartz. They are also used in microscopy devices or as sensible instruments operation windows. They are also employed in large scale in optic-electronics and components for process control and sensors.

Regarding the protective windows of our study, a special care is needed with its surface treatment because the polish made in both sides of the component must guarantee that both sides will remain precisely parallel. The surfaces are polished with sand paper very thin in order to reduce the number of micro fractures on its surface. A special care with the polishing process speed is also relevant being executed very slowly in large periods of time and only in the end of this process an optical polish is applied. This care is essential in the protective windows manufacturing because that is the better way to achieve high surface regularity patterns, parallelism and quality finish.

3. TESTING THE LIFE EVALUATION FOR THE PROTECTIVE WINDOWS

In order to try to reduce costs concerning the use of protective windows, the first test was a replacement for a less noble kind of material, reducing also acquisition costs. (Ribolla, 2003). With these samples using alternative materials, six among nine samples presented cracks probably due to the thermal expansion coefficient characteristics (Figure 6). Crack is an unacceptable characteristic for a component whose function is to protect another optical component, because when it is handled together with the adaptive LASER optic head by the robots, could easily fall and let the focalization lens in dangerous condition. For the reason of an unsuccessful procedure for this first work, a second essay to reduce costs with this material was done using recovered protective windows (Ribolla, 2004). Only this second experiment has lead to a favorable way toward costs saving.

The procedure of the protective window recover begins with the removal of a thin layer of its surface on the process-exposed side. All the impurities must be removed without changing its original quality such as surface regularity and parallelism between both sides. After the thin quartz layer removal, the surface is sanded and a coating is re-applied

Based on the results of this second essay (protective window recover), a lot of 10 quartz recovered samples was tested to see if the results would remain the same. The tests were performed and a follow-up was performed until their complete degradation. Data such as date, start time, end time and amount of body-in-white welded were recorded. Sample routine care involving identifications and non-stop tests was taken. Considering that the behavior of the samples were unknown regarding its narrowed thickness, a special observation was applied always to the firsts body-in-white welded. The thickness of the samples was between 1,32mm and 1,4mm and its transmittance rate was between 99.5% and 99.9% to the 1064nm wavelength. Considering these values, no protective window sample presented cracks or abnormal adherence on its surface (Ribolla, 2005) and after this test, all the protective windows were considered approved. The gains obtained with the costs saving using this procedure can vary between 20% and 54% if compared to the costs using new ones considering that the process of protective window recovery will be performed in lots with minimal amounts pre-negotiated. Depending on the type of protective window, the price of its acquisition becomes lower than its recovery costs. In other words, it is not always advantageous to recover any type of protective windows instead of buying it.

4. IMAGE ANALYSIS

Before the image analysis results be exposed, an interesting phenomena could be noticed among the samples, however with higher intensity on those whose degradation was more intense: In the central region of those samples, the spatter that have initially adhered to the protective window surface has ended up loosen and this characteristic allowed an increased amount of radiation to cross the protective window section. This characteristic was not observed near their borers. Maybe this fact can be explained considering the higher power density in this region and also explained by the huge difference between the thermal expansion coefficient for the steel (12x10-6°C^{-1}) and for the quartz (0.54x10-6°C^{-1}), this characteristic can lead to the rupture of the previous quartz-steel union. In the same central region the dominant color found tends to brown due to the high calcination of adhered impurities on the protective window surface. Near the border the color remains in gray scale This phenomena, at the same time that leads to a delay of the protective window replacement, also increases the risk of damage to the focusing lens once that the central part still enables the LASER beam across the section and the border of the protective window works like a LASER beam barrier. The image analysis was performed by a software built on JAVA and named ImageJ. As public domain software, it can be found in the internet. The steps taken to achieve the final result were: high resolution of the protective window digitalization, contours definition, effective area used and non-used and binary image conversion. (Figure 07).

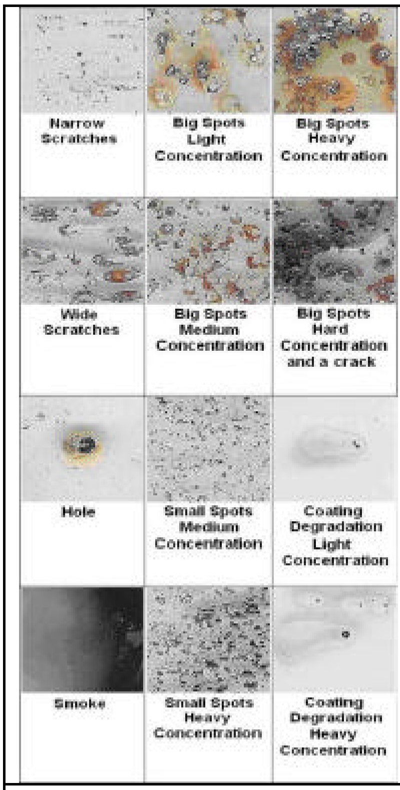

Figure 05 - Most common standards of degradation of protective windows.

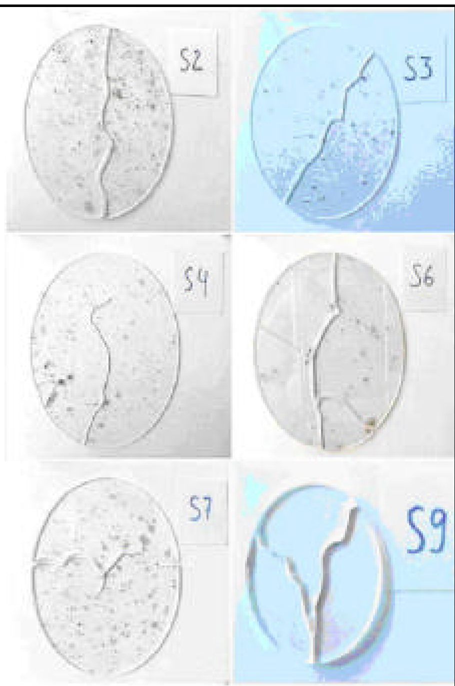

Figure 06 – Cracks presented in almost 60% of the samples.

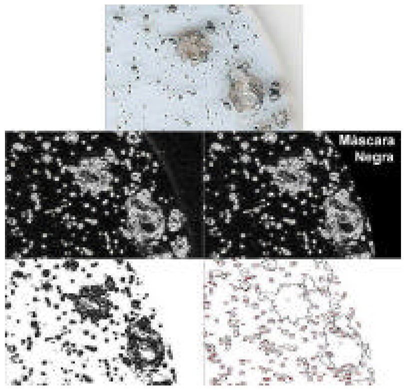

Figure 7 – Different steps applied to the process of image analysis.

In the extent of the particle analysis through images, the result found in a previous analysis of the spoiled surface, determined a pattern in relation to the replacement of the protective window because among the 48 samples studied, a common degradation rate was found. The average was 15.18% (285mm²) and standard deviation was 4.19% (78,69mm²). The total useful area considered was (1877.67 mm²). This result shows a practical coherence related to the needs of replacement of the protective window, even more because this replacement occurred in different parts of the day and was performed by different professionals. Samples with high degradation rates exposes many spatter marks with half moon shape, endorsing that in fact there is a high level of particle detachment, specially in the central protective window region. This characterization can be made with the stereology help, defined as an assemble of relations and procedures that allow to infer the geometric proprieties of a three-dimensional microstructure starting by measures and observations taken from bi-dimensional representative images of the same structures. (RUSS, J.C. et al, 1999).

5. CONCLUSIONS

Once the degradation parameters tolerances obtained from experimental results and image analysis are known for a particular LASER weld station and moreover knowing the requirements of the measured station, such as used LASER power, working angle average for the adaptive LASER optic head and length of the weld cords, it is possible to estimate for other work stations what would be the maximum degradation rates and consequently allow to know the better time for the protective window replacement in order to keep process quality and reduce costs with excessive protective windows replacement. In parallel, when the replacement is needed, the protective window recovery is nowadays more advantageous and a good alternative.

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EMISSAO DE RESPINGOS SOBRE JANELA DE PROTEÇÃO USADA EM SITEMAS DE SOLDA A LASER EM CELULAS DE MONTAGEM DE CARROCERIAS AUTOMOTIVAS

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***Abstract**: Este trabalho visa um estudo de caso sobre respingos em janelas de proteção usada em sistemas de soldagem a laser. O componente é empregado em na montagem de carrocerias automotivas por soldagem/brasagem a laser visando proteger componentes opticos mais caros do cabeçote de radiação LASER contra respingos, glóbulos e névoas, vapores metálicos e fumos. A manutenção e a substituição deste componente acrescenta um custo razoável ao processo de manufatura. Sua substituição ponderada por um índice de degradação ainda não está bem definida, e resulta sempre em ruptura do ciclo de manufatura, causando demérito na qualidade do produto ou aumentando seu custo.A metodologia exposta aqui se justifica em função do reduzido numero de fabricante destes dispositivos e a proposta deste trabalho foi a de criar um índice de desgaste pelo acumulo de respingos que permita avaliar o momento mais adequado para a sua substituição, maximizando sua vida em serviço sem que isto afete a qualidade do produto final.*

Key-words: Nd-YAG, laser, soldagem, respingos