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INVESTIGATION OF INFLUENTIAL PARAMETERS ON SHOT-PEENING OF ALUMINUM ALLOYS

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ABSTRACT
Modern high-speed ships demand application of materials that are light and with a good fatigue strength and corrosion resistance. Various aluminum alloys can be technologically improved to match these demands. It is known that shot-peening method can be applied to improve fatigue properties of aluminum alloys. However, the quality of the results obtained by this method is very sensitive to various parameters. This paper presents results of the investigation of some influential parameters, like nozzle angle and peening distance, on shot-peening of aluminum alloy Al2024-T3 that can be used in production of new types of high-speed ships in Croatian shipbuilding. Presented experiment results indicate the importance of a careful selection of shot-peening parameters since adversely chosen parameters can even lead to the aggravation of material properties.
Keywords: shot-peening, Al 2024 alloy, fatigue strength, nozzle angle, nozzle distance, peening pressure

1. INTRODUCTION

It is known that the shot-peening is a technological process that is successfully applied in the aircraft production for enhancing various material properties, i.e. for increasing fatigue strength of the material and strengthening crystal layers of the material, for prevention of corrosion and emerging micro-fractures and for removal of friction and forging effects [1, 2]. Also the process is used for decontamination of material surface as well as for the creation of smooth surfaces (low roughness) for painting purposes. These material properties are also very important for modern shipbuilding [3] that tends to produce faster and faster ships build from light materials like various aluminum alloys [4, 5]. The quality of shot-peening process, for shipbuilding purposes, depends on a large number of parameters that have to be well estimated and rigorously applied in order to achieve positive results. Experience showed that poorly chosen peening parameters may even decrease the properties of treated materials [6]. The number of influential parameters on the shot-peening process is large: type, size and shape of the shots, time of peening, stream velocity, air pressure on the peened element, distance from nozzle to material surface (peening distance), nozzle angle, peening intensity and surface coverage percentage. Experience showed that some of the parameters may be taken as constant while others must be evaluated through experiments and numerical simulations [7, 8]. The proper estimation of peening parameters is particularly important in cases where shot-peening is applied for modeling of ship structural elements, like hull plating and decks, known as peen-forming and is becoming increasingly important in production of high-speed and super-high-speed ships [9]. Shot peening is commonly conducted in a closed cabinet designed to safely confine the media and provide proper aiming of the shot blast stream. The modern shot-peening procedure utilizes CNC machines thus shortening the production interval for four times and includes a time required for post-peening, i.e. relive stress treatment. The post-peening process options include facilities for sanding to improve aerodynamic smoothness and aesthetic appearance, and a finish peening station to fine-tune stress corrosion resistance and fatigue life. The later is for use when the workpiece is very thick, requiring larger-sized shot for forming and smaller shot for finishing. The shot-peening process distorts topographic fineness of element surface in a way that it smoothens rough surfaces and increase harshness of smooth surfaces in accordance with shot diameter and material. Typically it is not desirable to apply any technological treatment on already peened element. But in cases when it is necessary, due to some production reasons, to treat the element after peening it is admissible to improve finished surface by grinding, ironing or heat treatment. The temperature limitations for treatment after shot-peening are given in Table 1.

Table 1: Admissible treatment temperatures after shot-peening

Material	Various steels	Al-alloys	Magnesium	Titanium
Temperature (º C)	220	100	100	260

Technical drawings of elements intended to be shot-peened must have clearly displayed requests for peening quality: type and size of shots, peening intensity and coverage percentage. All other parameters like stream pressure, nozzle angle, nozzle distance from element surface, element velocity, etc. are usually determined experimentally.

2. THE INFLUENCE AND CHOICE OF PEENING PARAMETERS

The aim of the controlled shot-peening process is to create compressively stressed surface layer on the peened element. The depth of the compressive layer has to be constant for every treated element and since it is practically impossible to determine stress distribution on complex elements without destruction, the total control of the shot-peening process becomes imperative. The selection of the compressive stresses and the depth of the compressive layer as well as the coverage percentage of treated structural element are based on the carefully selected combinations of the remaining parameters of the peening process. The choice of parameters is also related to the relative velocity of structural element and shot stream, thus it must be assured that peening procedure is simply and safely repeatable, i.e. the process should be automated and this can be achieved by utilization of CNC machines. If all the peening parameters are properly chosen the shot-peening treatment increases dynamic properties of structural element [10]. If that is not the case, the treatment will result in reduced dynamic properties which may be expected in complex elements like integral plates of high-speed ships that have different thickness throughout element and have attached supporting elements like frames and longitudinals [5, 10]. The negative effects of shot-peening treatment in integral plates occur when basic material is cold rolled and dumps and craters created during process may cause early emergence of cracks in material. This happens if the same shot-peening parameters are chosen for the entire plate even if it varies in thickness from side to side. The situation can even get worse if the process has high dynamic loading regime. Another undesirable effect that results in decreasing of material properties is overpeening. It happens when peening parameters are poorly combined, for example when coverage percentage is high, P_r = 200% and peening intensity ranges between 0.22 and 0.25 [8], although all the parameters individually satisfy standards (MIL-S-13165 i CEN). There are some new techniques that may help in choosing of peening parameters [11]. However in order to determine the proper peening parameters as well as the combination of parameters it is still necessary to perform experiments previous to the treatment of the real structural elements.

3. SHOT-PEENING CONTROL PROCESS

In practice the shot-peening control process includes the control of peened element and the control of the peening process itself. The control of the shot-peening process means periodic controlling of the following important factors: main characteristics of shots (size, shape, quality), all systems of the peening machine, flow of the air and shots, velocity along x, y and z axes, quality of filters, dusters and separators and every other factors that can influence the quality and reliability of the peening process. The control of peened element includes: control based on the experience without damaging element in production conditions and control through calculations and measurement of stresses in laboratory conditions that includes damaging of structural elements. Quality control of the shot-peening process in production conditions is performed by determination of peening intensity I, based on measured deflection of the standard test specimens. The shot-peening parameters of the test specimens are commonly determined by standard Almen method for intensity measuring and by constant measuring of the stream flow in the peening machine. In laboratory conditions a number of non-destructive methods may be applied like photoelectric, acoustic (ultrasound), electromagnetic, neuron diffraction, X-ray method, etc. Anyhow, the standard Almen method remains the simplest and accurate enough for the application in production conditions and thus it was applied in the experiment presented in this paper. The parameters of conducted experiment presented in this paper were selected in accordance with the recommendations for Al-alloys in SAE manual and AMS2430 and MIL-S-13165-C given in the table 2.

Table 2: Recommended peening intensity for Al-alloys

Thickness (mm)	Intensity *I* (steel shots)	Intensity *I* (glass shots)
Less than 0,23		0,004 to 0,008 N
0,23 to 0,9525	0,006 to 0,010A	0,008 to 0,012N
More than 0,9525	0,010 to 0,014 A	0,012 to 0,016 N

For the experiment the following relations between peening parameters were taken:

- I (Almen A2) = I (Almen C2) × 3,5 and
- I (Almen N2) = I (Almen A2) × 2,5.

Established relations between intensity gained for the standard specimen and that of peened material, regarding the height of deflection on the specimen, are showing the size of the residual stresses entered in the material by shot-peening and thus they are showing the increase of the fatigue strength. According to that requests for intensity, the covered percentage of element surface (P_r) and size (diameter) of shots are entered in the production documentation. The deflection on specimen was measured by Almen-comparator. Intensity depends on the time of peening. Saturation curve is gained by conducting a series of test with same parameters and on the same equipment but different time of peening, *t*. Special attention has be paid to the selection of shot type, size and hardness, since these parameters are very influential on the depth of compressive layer, particularly regarding elements that have higher hardness than Almen specimen.

4. EXPERIMENT RESULTS

Tests were performed in laboratory conditions on the following equipment: Machine CNC VAPORBLAST (Paris) for shot-peening, hydraulic pulsation machine type SCHENCK with 0-250 kN for dynamic loads and Almen comparator with Almen test specimens type N for control.
Tested specimens were flat and material used was Al 2024 in state T3 with chemical and mechanical properties given in Table 3.

Table 3: Properties of the tested material

Alloy	Cu%	Mg%	Mn%	Si%	Fe%	Li%	Zr%	R_m N/mm^2	$R_{p0,2}$ N/mm^2	A_5 %
2024-T3	3,9	1,5	0,5	0,4	0,2	-	-	440	290	18-20

Specimens were of different thicknesses: 1,2 mm, 2mm and 4mm. Tests were performed at constant amplitude with periodic loads and in the air and the room temperature. Figures 1, 2, 3 and 4 presents obtained experiment results.

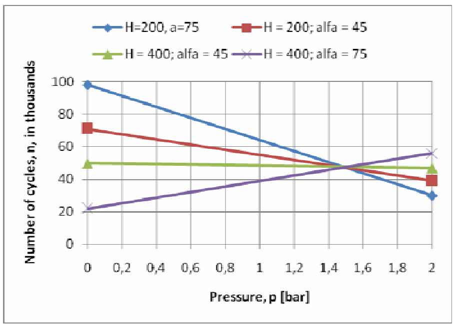

Figure 1. Influence of the peening pressure, p

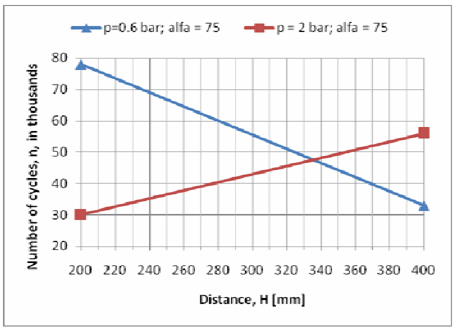

Figure 2. Influence of the nozzle distance, H

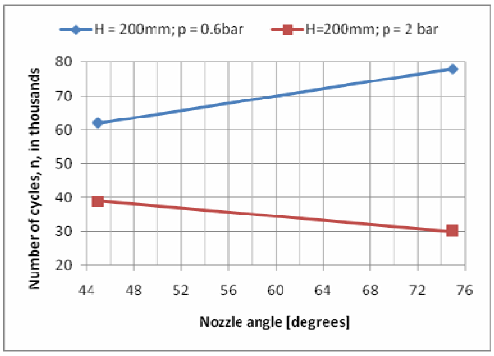

Figure 3.Influence of the nozzle angle,alfa (relative to the surface of peened element)

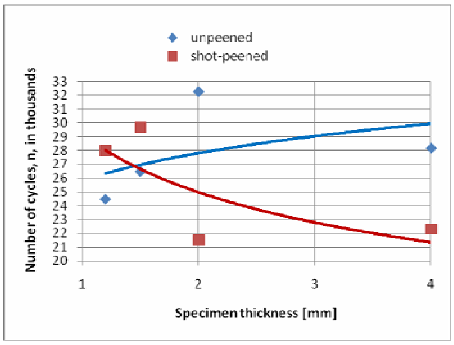

Figure 4 Fatigue strength of specimens of different thickness

5. CONCLUSION

The shot-peening is low cost, reliable and easily repeatable procedure that can be used not only for increasing material properties, like fatigue strength and corrosion resistance, but also for shaping structural elements. It is pointed here that defining the proper process parameters is of vital importance for the application of peen-forming. Inadequate choice of process parameters can lead to over-peening, which causes decreasing of material mechanical properties. In case of shot-peening of elements of varying thickness it is necessary to apply the procedure in two or more steps because for the different thicknesses the different peening parameters must be applied. It can be done by protecting (masking) a part of the surface that requires different set of parameters to achieve the best results. Then, when the rest of the surface has been treated, the masked part is unmasked and peened with different peening parameters and at the already peened surface is now masked for protection. The paper concludes that theoretical and numerical methods which describe the peening process are very complex and practically only preliminary utilizable and thus the experiment remains the primary way for determination of the adequate process parameters.

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