Analysis of the effect of shot peening on mechanical properties of steel sheets used as screener sieve materials

M Śledź, Ł Bąk, F Stachowicz and W Zielecki
Rzeszow University of Technology, Powstańców Warszawy 8, 35-959 Rzeszów, PL

E-mail: stafel@prz.edu.pl

Abstract. Numerous studies have been performed in an attempt to improve fatigue strength of materials by creating compressive residual stresses in the surface layers as a result of the shot peening process. It was shown that the process is highly effective when dealing with particular parts of the body (detail) needed special attention. In this case, those are parts of screen sieve plate situated near the fixed edge and undergo the largest deformation caused by impact bending and thus need a special treatment. In this paper, the results of experimental tests are presented to analyse the effect of microshot peening on mechanical properties, surface layer characteristics and fatigue strength of steel sheet specimens. The data obtained from our experiments can be used for numerical simulations to design details with improved fatigue resistance.

1. Introduction
Screening is one of the basic technology in mechanical processing of granular materials. Vibrating screen is widely used for grading and screening materials in the following fields: minerals, quarry, building materials, etc. The parts of screen sieve plate which are located near the fixed edge undergo the largest deformation, caused by impact bending during the separating screener exploitation. Taking also into account energy dissipation associated with the process, it is extremely important to have a suitable material for screen sieve plate. One of the methods to enhance the fatigue strength of material used for screen sieve is shot peening.

Shot peening is a process where the surface of a detail of its component is bombarded with small spherical particles called shot. It is widely used to improve the fatigue strength of material through the creation of a compressive residual stress in their surface layers [2-6]. Depending on the character of the forces acting on the surface during the process, one distinguishes static and dynamic peening [7]. The shots impart small indentations (or dimples) on the striking surface leading to a deformation of the surface. In an attempt to return yield surface to its initial shape, residual compressive stresses appear in the surrounding elastic material forming the cold work hardened surface layer. Compressive residual stresses in the surface layer increase the fatigue strength of the sieve material, and therefore may be beneficial in reducing the fatigue damage. Due to the shot peening, the surface layer of material is caused to yield plastically under the impact of shot. Residual compressive stresses result from the inability of the plastically deformed material to reaccommodate itself on the elastic subsurface. The following mechanical properties of the design material maybe improved as a result of the shot peening process: resistance to fatigue, stress corrosion cracking, fretting, galling, erosion and closing of pores [4]. The tall orders of the burnishing process are materials with hardness above 45 HRC [2].
experimental investigations show, that the shot peening has the good influence on fatigue strength of the constructional steels [3], spring steels [4, 6], titanium alloys [7]. The shot peening results depend on various parameters such as shot size, velocity, shape, material, coverage, hardness, intensity, etc. The shot peening results have been widely studied theoretically and experimentally [2-9].

In this work, one of the burnishing methods (pneumatic shot peening was used. The machine for pneumatic shot peening has been developed in the Rzeszow University of Technology with the aim to increase the fatigue strength of low and medium hardness in medium and small lot production. This process is characterized by small overall dimensions, low costs, quiet operation and a perfect quality of constituted surface layer. It has been shown [10] that application of the pneumatic shot peening process to ground surfaces may cause even elimination of subsequent polishing operation. The research has shown its great effectiveness when it comes to the fatigue of constructional steels about 10-40%, titanium alloys about 10-20 %, steels with layers about 5-25 % [11], spring steels about 30-40 % [12]. Parameters of the burnishing done by the pneumatic shot peening play however a decisive role to provide desirable properties. Moreover, without proper tuning, it might cause the effects opposite to those one wants to achieve. This has been the main reason to conduct the research which main goal is to determine optimum parameters of pneumatic shot peening providing the best properties for the each piece of machine [12].

In the presented experimental investigations, the particular part of the screen is shot peened. We use the 3 mm bearing balls accelerated to a suitable speed, by the blast of the compressed air. The pneumatic shot peening process has been realized using one or a few nozzles consisting of lower and upper nozzle (figure 1). As usual, the lower nozzle is installed directly on working chamber bottom and made in form de La Valla nozzle, supported compressed air by pressure of 0.15-0.6 MPa. The nozzle task is produce stream air about large linear velocity which captures balls from chamber bottom and directed through upper nozzle on workpiece. Balls bang on the reinforcement surface with the speed limit of 3-8 m/s, and after the returning, they go down to the bottom of the chamber and then they are reused for the process. During the burnishing, the reinforced piece of the machine moves in order to provide the full coverage of the element with the signs of the treatment [11]. Kinematics movements should make possible achieving 100% coverage of the workpiece. This process itself is affected by ejector nozzle geometry and: ball diameter, air pressure, working nozzle to workpiece, and peening time [10].

Figure 1. Scheme of ejector nozzle and pneumatic shot peening: 1 - balls, 2 - working chamber bottom, 3 - workpiece, 4 - upper nozzle, 5 - lower nozzle.
2. Material and experimental procedure
In the modified version of screener, 1 mm thick perforated steel sheet metal is used as its sieve (figure 2). Four different kinds of the steel sheets were used in experimental investigation: 1.0530; 1.4301; 1.8159 and 30HGSA. Both specimen surfaces have been subjected to pneumatic shot peening. The uniaxial tension test and rotating bending fatigue tests were performed with two types of specimens: peened and unpeened to examine the effect of the process.

When the mechanical testing is concerned, tensile specimens of 240 mm gauge length and 12.5 mm width were prepared from strips cut perpendicular to the rolling direction of the sheet. During experiments, we recorded simultaneously the tensile load, the current length and the current width of the specimens.

Specimens dimensions used for fatigue testing were 30 x 100 mm. The rotating bending fatigue test was conducted on the special test stand which was built on the basis of a Wöhler type testing machine ETS at a frequency of 300 cycles/s. During the investigation the specimen was placed in the hydraulic handle (figure 3) which has a constant strength of interlocking and can lead to the resonance vibration. Specimen undergoes vibration until the cracking and/or gaining final number of cycles. During the research there were $2 \times 10^6$ accepted cycles.

Figure 2. Scheme of the vibrating screen geometry.

Figure 3. Vibratory stand used for fatigue test.
3. Results
As a result of pneumatic shot peening, the surface of the sheet specimen has been covered with small dimples (figure 4). The results of uniaxial tension test (table 1 and 2) demonstrate visible change in the mechanical parameters after the shot peening. Among others, the following conclusions can be drawn:

- The value strain hardening exponent obtained for peened specimens is lower than that of unpeened sheet specimens for all tested materials.
- Shot peening process has no evident effect on the value of yield stress and ultimate strength.
- Large difference, however, can be observed for tensile characteristic, especially in the case of materials with physical yield point - 1.8159 steel and 30HGSA steel (figure 5).
- Shot peening of sheet surface resulted in decreasing in the value of total elongation.
- The process has the lowest effect on the value of plastic anisotropy factor.

Figure 4. Surface of 1.4301 steel sheet: before pneumatic shot peening (left) and after pneumatic shot peening (right).

### Table 1. Mechanical properties of the sheet metal tested before shot peening

| Sheet material | Yield stress $R_{p0.2}$ MPa | Ultimate strength $R_m$ MPa | Total elongation $A_{50}$ % | Strain hardening parameters | Anisotropy factor $C$ n r |
|----------------|-------------------------------|-----------------------------|----------------------------|-----------------------------|-------------------------|
| 1.0530         | 316                           | 516                         | 30                         | 864                         | 0.193 1.356             |
| 1.4301         | 315                           | 708                         | 51                         | 1547                        | 0.441 0.779             |
| 1.8159         | 212*                          | 409                         | 24                         | 1105                        | 0.234 1.083             |
| 30HGSA         | 377*                          | 580                         | 27                         | 1082                        | 0.242 1.606             |

### Table 2. Mechanical properties of the sheet metal tested after shot peening.

| Sheet material | Yield stress $R_{p0.2}$ MPa | Ultimate strength $R_m$ MPa | Total elongation $A_{50}$ % | Strain hardening parameters | Anisotropy factor $C$ n r |
|----------------|-------------------------------|-----------------------------|----------------------------|-----------------------------|-------------------------|
| 1.0530         | 332                           | 495                         | 28                         | 784                         | 0.147 1.334             |
| 1.4301         | 357                           | 733                         | 44                         | 1522                        | 0.387 0.757             |
| 1.8159         | 208                           | 590                         | 23                         | 896                         | 0.141 1.104             |
| 30HGSA         | 390                           | 580                         | 24                         | 887                         | 0.156 1.750             |
Based on results of the uniaxial tension test one can conclude that the 1.4301 steel seemed to be a good material for screener sieve. It is also noteworthy that the stainless austenitic chromium-nickel steel 1.4301 shows good corrosion resistance (particularly in natural environment) and weldability. For this steel sheet, fatigue test has been also performed. Results of the bending fatigue in the form S-N curves (figure 6) clearly demonstrate the shot peening benefits. Thus for example, fatigue strength of peened specimens increased above 100 MPa in comparison to that of unpeened specimens. The reason for such an improvement can be attributed to the formation of compressive residual stresses in the surface layer of the material as the result of the shot peening [4]. As compressive stresses are introduced into the surface, fatigue cracks not easily initiate in neither propagate through an area under compression. As a result, the improvement in bending fatigue strength has been achieved. Due to increase their fatigue strength, the shot peening process is specifically recommended to burnishing of metallic parts undergoing dynamic loading. Comparison of the results presented in figure 5 and 6 confirms that the effect of the shot peening is more pronounced in the case of fatigue strength testing than in the uniaxial tensile.

4. Conclusion
The influence of a shot peening treatment on the mechanical properties of different steel sheets have been investigated. The results of uniaxial tension test demonstrate that shot peening resulted in significant change in the mechanical characteristics and improve fatigue
strength. Thus, the use of shot peening of sheet surface made it possible to increase fatigue life of screener sieve.

![Figure 6. Effect of shot peening on fatigue testing of the 1.4301 steel sheet.](image)

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**References**

[1] Dyr T, Wodziński P 2002 Model particle velocity on a vibrating surface *Physicochemical Problems of Mineral Processing* **36** 147-157

[2] Przybylski W 1987 *Technologia obróbki nagniataniem* (WNT Warszawa)

[3] Torres M A S, Voorwald H J C 2002 An evaluation of shot peening, residual stress and stress relaxation on the fatigue life of AISI 4340 steel *Intern. J. of Fatigue* **24** 877-886

[4] Tekeli S 2002 Enhancement of fatigue strength of SAE 9245 steel by shot peening *Mater. Letters* **57** 604-608

[5] Gao Y K, Lu F, Yin Y F, Yao M 2003 Effects of shot peening on fatigue properties of OCr13Ni8Mo2Al steel *Mater. Sci. and Technol.* **14** 372-374

[6] Aggarwal M L, Agrawal V P, Khan R A 2006 A stress approach model for prediction of fatigue life by shot peening EN45A spring steel *Int. J. Fatigue* **28** 1845-1853

[7] Zaleski K 2009 The effect of shot peening on the fatigue life of parts made of titanium alloy Ti-6Al-4V *Maintenance and Reliability* **4** 65-71

[8] Nakonieczny A 2002 *Dynamiczna powierzchniowa obróbka plastyczna. Kulowanie. Shot peening* (Instytut Mechaniki P precyzyjnej Warszawa)

[9] Bagherifard S, Ghelichi R, Gaugliano M 2012 Numerical and experimental analysis of surface roughness generated by shot peening *Appl. Surface Sci.* **258** 6831-6840

[10] Łunarski J, Zielecki W 1990 Possibilities of improving fatigue properties of machine elements by pneumatic shot peening *Proc. ICSP 4 Tokio* pp 263-272

[11] Zielecki W 1990 Improvement fatigue properties after pneumatic ball peening *ZN PRz, Mechanika* **22** 59-67

[12] Zielecki W 1987 Influence of pneumatic shot peening on 50HF steel fatigue strength and surface condition *ZN PRz, Mechanika* **14** 35-40