Deep Cold Rolling of Almen Strips for Process Monitoring

G. G. Feldmann[1], E. Mueller[2]

[1]Rolls-Royce Deutschland Ltd & Co KG, Oberursel/Taunus
[2]Steinbeis GmbH & Co. KG,-Transferzentrum für Federntechnologie, Iserlohn
[2]Hochschule Bochum, Fachbereich Mechatronik und Maschinenbau, Bochum

Abstract:
Nowadays high durability and high efficiency of components compared with lightweight construction and cost effective processes set high demands on manufacturing industry. To meet these requirements additional processes to increase component properties are used. Some of them like shot peening reach their limit to fulfil the requirement for enhancing fatigue strength of components and resistance against damage. More and more deep cold rolling (DR) or low plasticity burnishing (LPB) is used to improve the finish quality and to introduce deep residual compressive stresses to mitigate crack initiation and crack propagation. Shot peening uses the Almen strip method, which enables a comparability of different peening processes through quantifying the intensity of the process by using thin strips of SAE 1070 steel. LPB uses a load folk to adjust and control the forces. This paper gives an insight into the capability of Almen strips used for process monitoring of different deep rolling applications.

Keywords: mechanical surface treatment, deep rolling, cold rolling, low plasticity burnishing, x-ray diffraction, residual stress, Almen strip

Introduction

Shot peening processes are today used in nearly all areas of mechanical engineering to generate even surface finish and to induce residual compressive stresses. To enable comparability between different shot peening operations, used treatment parameters and different equipment J.O.Almen invented a method using spring steel strips. These Almen strips allow fast and cheap monitoring of shot peening processes.Using residual stress measurement for such a monitoring is too expensive and last too long. The integral method to measure the Almen arc height gives sufficient information about the consistent of the shot peening process. Today in more cases deep cold rolling (DR) or low plasticity burnishing (LPB) is used to improve finish quality of component surfaces and to introduce deep residual compressive stresses into subsurface layers to increase fatigue strength.This investigation is based on the question: Is the Almen strip method as well a feasible method for monitoring deep rolling processes. Which boundary conditions have to be fulfilled to get meaningful data?

Basics

Almen Strips

To enable comparability Almen strips are standardized in three different categories N, A and C which relates to their thickness. During the peening process compressive residual stress is induced into the strip. The strip looses its inner balance and develops a curveted shape to reach it again. This deflection height or arc heights is used to assess the intensity of the peening process. To cover different intensity grades different Almen strip thicknesses (0.79 mm, 1.295 mm, 2.385 mm) are used related to the categories N, A and C. Detailed information about the characteristica of Almen strips can be found in (BA 12). The principle procedure is shown in Fig. 1.

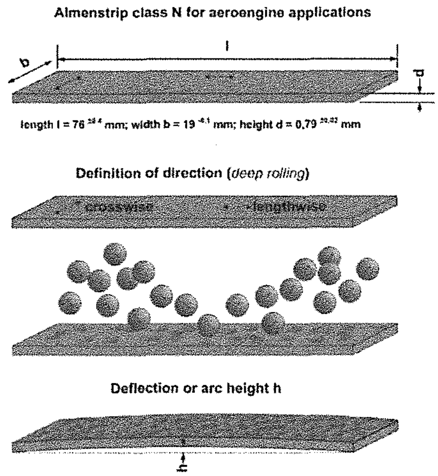

Fig. 1: Schematic view and definitions of Almen strips and there parameters (FE 12: 32)

The shot peening treatment is described by two discontiguous characteristic parameters the intensity and the coverage. The intensity is a result of a saturation curve generated by treating a number of Almen strips with constant parameter but different treatment times shown in Fig. 2. The coverage is assessed on the real component and needs to be nearly 100 % to generate a most uniform surface finish and residual compressive stress state shown in Fig. 3. Both characteristic parameters depend on a variety of variables whereby the intensity shows the capability of the process and the coverage shows the capability of the process on a specific material and geometry.

Intensity
Almen intensity is defined as the deflection or arc height of the Almen strip where a doubling of the treatment time does increase deflection height of 10 %. The increasing number of hits on the surface increases the deflection during the shot peening treatment of the Almen strip until saturation occurs. For deep rolling the distance between the rolling tracks can be varied to generate a saturation curve. The saturation time T depends on the treatment parameters e.g. shot or rolling ball diameter and material, shot velocity or rolling pressure.

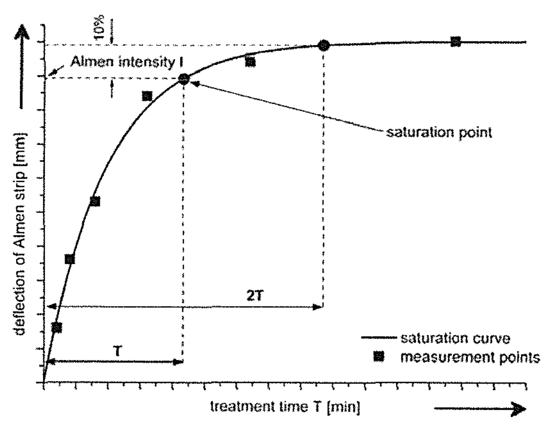

Fig. 2: Deflection of an Almen strip in dependence of the treatment time (FE12: 33)

Coverage
Coverage is defined as the amount of hit by shot area to treatment area. An increase of the treatment time leads to an increase of the coverage shown in Fig. 3. The gradient of the curve decreases with increasing treatment time caused by repeatedly hits on identical surface. This degressive increasing curve is theoretically not able to reach a value of 100%. This is the

reason why the 'full coverage' was defined as 98 %. Fig. 3 shows the relation between treatment time and coverage level. The coverage is standardly used to define the amount of surface treatment on real component material. Due to the fact that the material of the Almen strip is mostly different to the real component material the elastic plastic deformation characteristics of both are different. The increase of coverage increases as well the residual compressive stress state until a saturation occurs.

Fig. 3: Coverage as a function of the treatment time (FE 12: 30)

Residual stresses

The aim of shot peening and deep rolling is to induce residual compressive stresses into the surface and subsurface layers. Fig. 4 shows typical distributions. Characteristically is the bellied distribution with a residual compressive stress maximum below the surface. Some cases depending on the treatment parameters and material characteristics show as well hardness increase at the surface. Shot peening shows within orientation between 85 and 95 degree to the peened surface no measurable difference between along and across measured residual stress states. To the contrary deep rolling shows always higher across the rolling direction measured residual stresses than along the rolling direction. (MU 03).

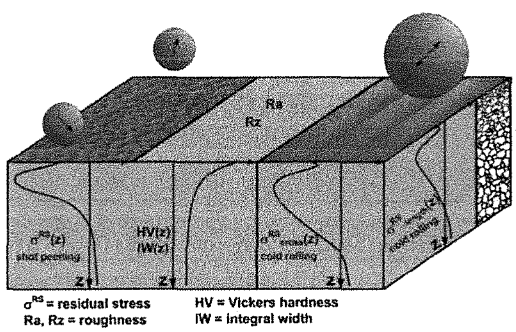

Fig. 4: The characteristic parameters concerning shot peening and rolling. (FE 12: 34)

Deep Rolling

The deep rolling process uses a ball or a roll with a certain ball diameter respectively profile radius of the roll. The three parameters rolling pressure, diameter of the ball or roll and track distance determine all values shown in Fig. 4. Fig. 5 shows additional factors defining the process. The track distance b defines the coverage C_{DR} that is the difference of the width of the indentation zone a and the track distance b divided by the track distance. The depth h_{DR} of the valley depends of the pressure force F and the hardness's of the materials. Detailed description is for example given in (BE 82, KA 84, KL 88)

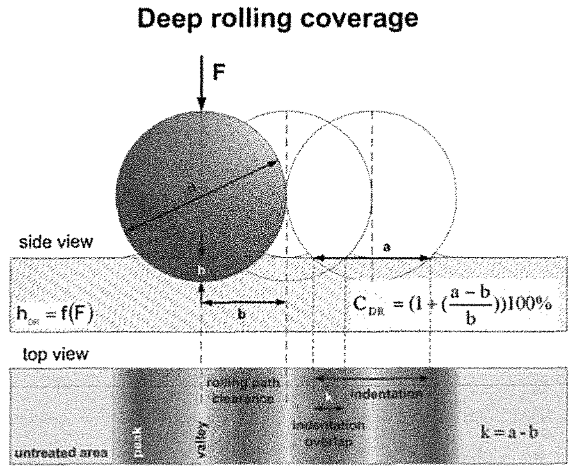

Fig. 5: Additional factors which characterise the deep rolling process (FE 12: 40)

Experimental Setup

Tooling

The rolling process was performed with hydrostatic tools of the HG-series with different ball diameters distributed by Ecoroll in Germany. The number x after the letters HG indicates the ball diameter in mm. (Details can be seen at the website: www.ecoroll.de). The tools can be used in standard e.g. drilling, milling or turning machining centers. The experimental trials were done using ball diameters of 3, 4 and 6 mm corresponding to the tools HG3, HG4 and HG6.

Strip mounting

For mounting the Almen strips special fixtures were designed and manufactured. The Almen strip treated with deep rolling were partly magnetically fixed or mechanically tightened with screws on the outer edges of the strips. In both cases a custom made fixture was manufactured to disable a lateral movement.

Results

With the tooling HG 3 and HG 6 class N Almen strips were rolled along and across the strip. For both tools a starting track distance with relatively high space between the tracks was chosen to enable the generation of a saturation curve. Fig. 6 shows the saturation curves of the HG3 tool deep rolled class N Almen strips results. The ordinate shows the deflection heights of the Almen strips above the axis of abscissas which show the normalized treatment time respectively coverage values. This approach is used to enable a direct comparability to the shot peening saturation curves.

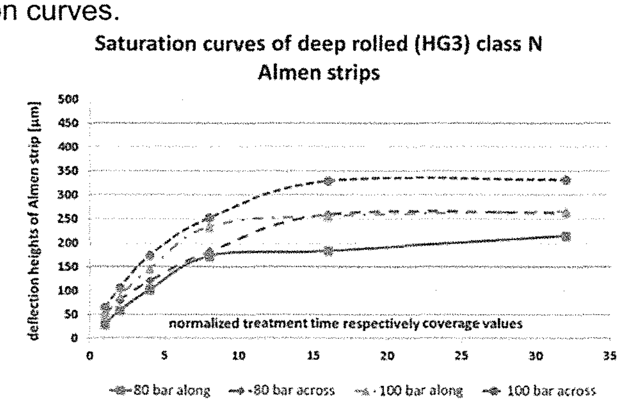

Fig. 6: Saturation curves of deep rolled (HG 3) class N Almen strips

The graph shows that an increase of pressure increases deflection heights. Furthermore the deflections of across rolled Almen strips higher than along rolled. At a normalized treatment time of around 15 no significant increase is visible, the saturation is reached. Transferred to the residual compressive stress state in the Almen strip, it can be said that a further increase of the treatment time respectively the coverage level does not lead to an additional increase of the residual compressive stresses (MU 03). The Almen strip is over the whole range of track distances sensitive for the rolling process. The saturation is not caused by the capability of the Almen strip but by the impact of the specific used parameter. Fig. 7 shows the saturation curves of the HG6 tool deep rolled class N Almen strip results which confirm the above made assumptions for the HG3 tool. In the case of the 80 bar across the saturation is not yet reached.

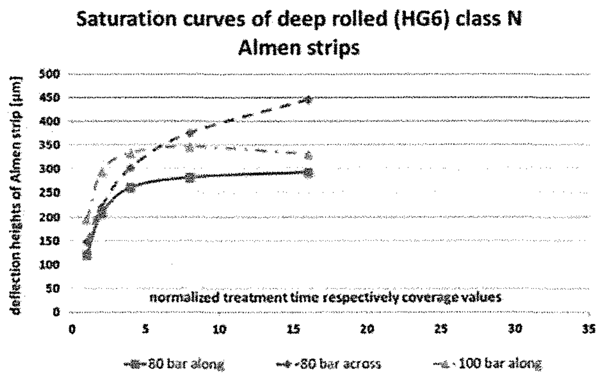

Fig. 7: Saturation curves of deep rolled (HG 6) class N Almen strips

The HG4 tooling was used to investigate the comparability of using different Almen strip classes over a wide range of parameter. Fig. 8 shows analog to the investigations of the HG3 and HG6 tooling the impact of different pressures and different rolling directions on class A Almen strips.

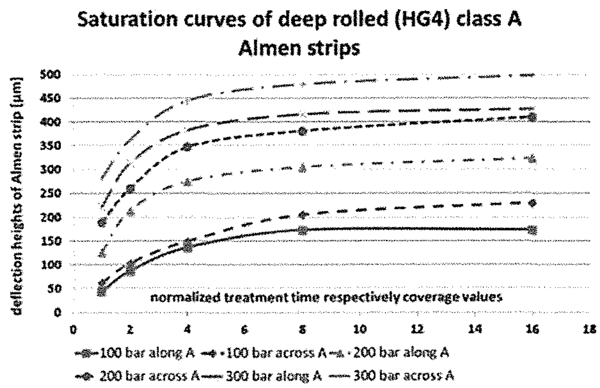

Fig. 8: Saturation curves of deep rolled (HG 4) class A Almen strips

Finally Fig. 9 shows the comparability between Almen strip class A and class C. The class A Almenstrips shows after equal treatment an approximately three times higher deflection than class C Almen strips. The thickness of class C is nearly twice the thickness of class A. Both observations fit to the knowledge of Almen strip shot peening behavior.
Residual stress measurements were done at Almen strips A with the HG 6 tooling at different pressures. The rolling direction was perpendicular to the strip with a track distance of 150 µm. (It was done with a slightly different area, because a more traditional strip holder was used. Therefore it is not directly comparable with the other deflections.) The Almen strips were in the equilibrium and the deflection was constant during the measurements in the depth, although a small amount of material was removed to measure into the depth. To get a better impression of the behavior an average of the residual stresses of the first 250 µm depth was done:

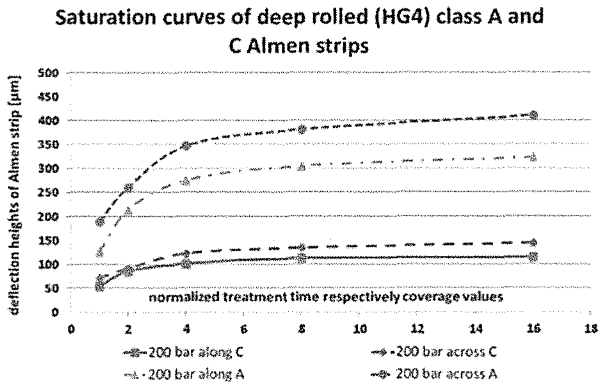

Fig. 9: Saturation curves of deep rolled (HG 4) class A and C Almen strips

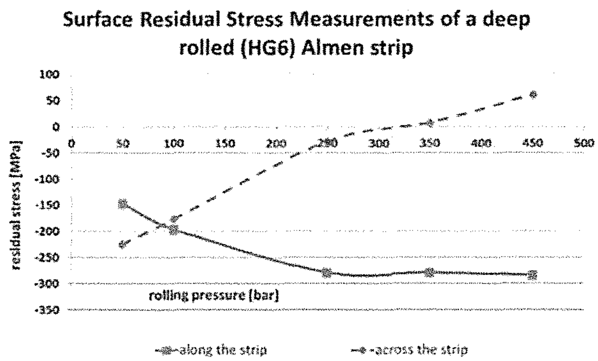

Fig. 10: Surface Residual Stress Measurements of a deep rolled (HG6) Almen strip

The measurement along the strips means perpendicular to the rolling direction and vice versa. The deflection of the Almen strip was linear between 50 bar and 450 bar from 0,056 mm to 0,614 mm. Fig. 10 shows the saturation from 200 bar for the residual stresses in the surface along the strip. The residual stresses across the strip increase almost linear with the pressure. This causes the linear increase of the deflection.

Conclusions

Almen strips can be used for monitoring a rolling process. The process monitoring can be used, where other methods like e.g. residual stress determination by x-rays is impossible caused by a complex geometry or used material. The residual stresses within the Almen strip can not be related to the residual stresses in the component.

References

BA 12 Baiker, S.: Shot Peening. MFN, Wetzikon, 2012 (ISBN: 978-3-033-03591-1)

BE 82 Bernstein, G. u. Fuchsbauer, B.: Festwalzen und Schwingfestigkeit, Z. f. Werkstofftechnik 13 (1982), p. 103 – 109

FE 12 Feldmann, G.: Verbesserte mechanische Oberflächenverfestigung von Schaufeln an integral beschaufelten Hochdruckverdichterrotoren. Shaker Verlag, Aachen, 2012 (ISBN: 978-3-8440-1050-3)

KA 84 Kaiser, B.: Schwingfestigkeitsteigerung durch Randschichtverfestigungsverfahren, VDI-Berichte „Werkstofftechnik", Düsseldorf (1984), p. 26- 37

KL 88 Kloos, K-H. u. Adelmann, J.: Schwingfestigkeitsteigerung durch Festwalzen, Mat.-wiss. u. Werkstofftechnik 19 (1988), p. 15 - 23

MU 03 Müller, E.: Comperison of the Residual Stresses Induced by Shot (Stress) Peening and Rolling in Spring Steel; in L. Wagner (Hrsg.): Shot Peening, S. 441 – 446, Wiley-VCH-Verlag, Weinheim 2003