Deep rolling of bore holes with a diameter of 3 mm with a hydrostatic tool

K. Röttger, S. Fricke

ECOROLL AG Werkzeugtechnik, Celle, Germany

Abstract
This paper shows how to deep roll a bore hole with a diameter of 3 mm. For this a new developed tool type "ball point", with a hydrostatic beard ball is used.

Keywords Deep rolling, bore holes, processing, boring, reaming, compressive residual stresses, fatigue.

Introduction

Deep rolling is similar to roller burnishing when deforming and positively influencing a component's rim zone characteristic. However, it is the only process to increase fatigue strength which combines

- the generation of compressive stresses,
- cold work in a material's rim zone and
- smoothing a component's surface and thus removing micro notches.

This combination can improve fatigue strength up to five times and therefore significantly increase the service life of a component. Deep rolling is especially recommended for components which underlie cyclic stress during operation and can therefore be destroyed by material fatigue.

Compared to alternatives, e.g. shot peening, not every component can be processed by deep rolling [1 - 3]. Especially certain free form shapes and other small shapes, e.g. small bore holes, couldn't be deep rolled. For a special customer application ECOROLL developed a hydrostatic tool to process a bore hole with a diameter of 3 mm. Before this, the smallest diameter to deep roll bore holes with a hydrostatic tool was 6 mm. The customer's application was a central valve. In use, the bore hole is subjected to a pressure of up to 4.000 bar. Shot peening of the bore hole was impossible. From the perspective of the customer mandralizing, another process to increase the life time of the component in the area of the hole would have been too expensive. The tests with the new developed tool, which uses two balls in opposite to each other (Fig.1, arrows) with a diameter of approx. 1 mm, have shown good results in improving surface quality. The surface characteristics in form of values like R_z and R_a have been improved. The increase in hardness and the residual stresses have not been measured.

Experimental Methods

Therefore ECOROLL has conceived a test body made of 42CrMo4 (low alloyed steel). The parameters, which have been used for deep rolling, are given in Table 1.

Table 1: Deep rolling parameters

Part	Preprocessing	Feed [mm/rev]	Pressure [bar]
1	Boring + reaming + deep rolling	0,03	400
2	Boring + reaming + deep rolling	0,03	100
3	Boring + reaming	-	-

Figure 1 shows the tool which has been used for the tests. During the introduction into the bore hole two balls are exposed and transfer the force, generated by an external hydraulic unit, onto the surface. By further feed the complete surface can be deep rolled. The balls with a diameter of 1.2 mm are arranged on opposite sides.

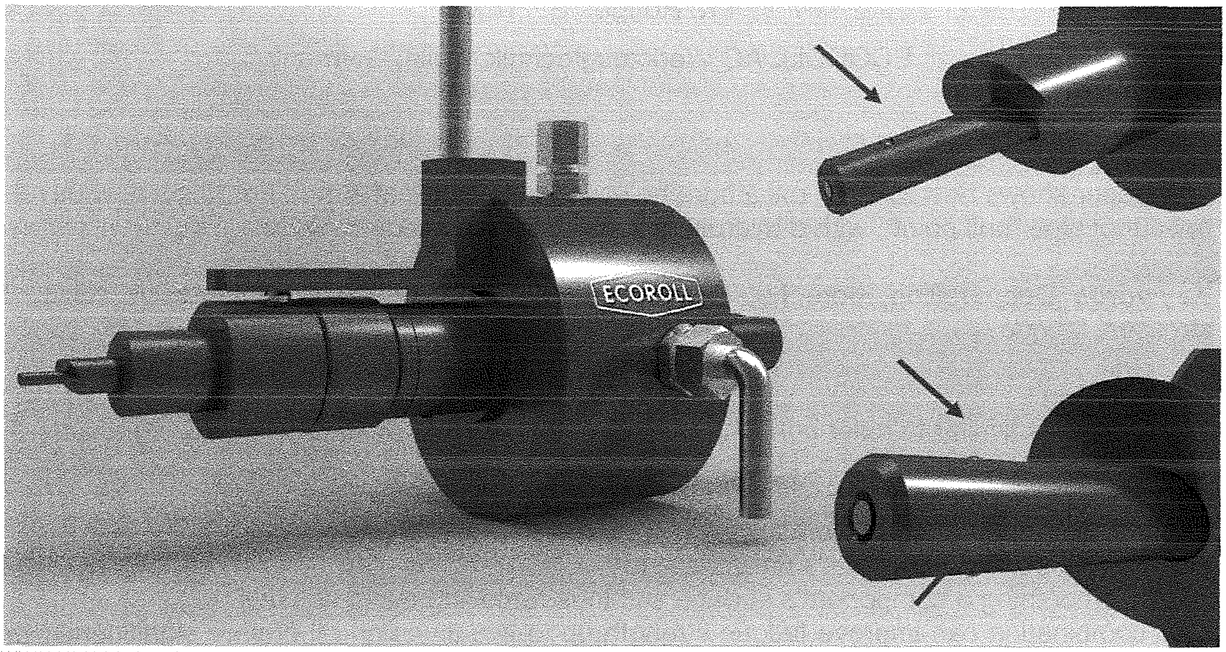


Fig. 1: Deep rolling tool HG1.2_11

Experimental Results

After the tests, the parts have been sent to company Stresstech GmbH, which split the parts (Figure 2) and measured the residual stresses and half-width via X-ray diffraction and electrolytic removal.

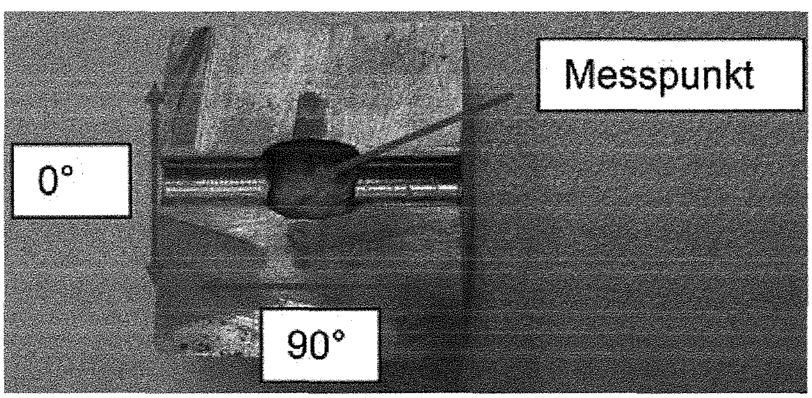


Fig. 2: Measuring of residual stresses and half-widths by Stresstech GmbH [4]

Table 2 and 3 show the values of the residual stresses measured transverse to the rolling direction and longitudinal to the rolling direction [4].

Table 2: Residual stresses measured transverse to the rolling direction

Distance [mm]	Part 1 (400 bar, f=0,03 mm/rev) [MPa]	Part 2 (100 bar, f=0,03) [MPa]	Part 3 (without deep rolling) [MPa]
0	-993	-698	-587
0,01	-738	-703	-495
0,025	-511	-606	-443
0,05	-412	-368	-398
0,1	-351	-285	-267
0,3	-121	-28	-20

Table 3: Residual stresses measured longitudinal to the rolling direction

Distance [mm]	Part 1 (400 bar, f=0,03 mm/rev) [MPa]	Part 2 (100 bar, f=0,03) [MPa]	Part 3 (without deep rolling) [MPa]
0	-366	-355	-288
0,01	-308	-365	-217
0,025	-213	-338	-158
0,05	-217	-290	-112
0,1	-196	-176	-133
0,3	-161	7	-45

The values for part 3 (without deep rolling) show already compressive residual stresses in the rim zone. However, by deep rolling the compressive residual stresses could be increased. The value one on the surface could be almost doubled (part 3: -587 N/mm^2 → part 1: -993 N/mm^2). You can also see, that the increase of the deep rolling force led to a deeper penetration. Additionally the values for compressive residual stresses measured transverse to the rolling direction are higher than those measured in longitudinal direction.
The respective curves are shown in the graphs 1 and 2.
The graphs 3 and 4 show the values of the half-widths measured transverse to the rolling direction and longitudinal to the rolling direction [4].
The measured values of the half-widths show an increase of the hardness by deep rolling.

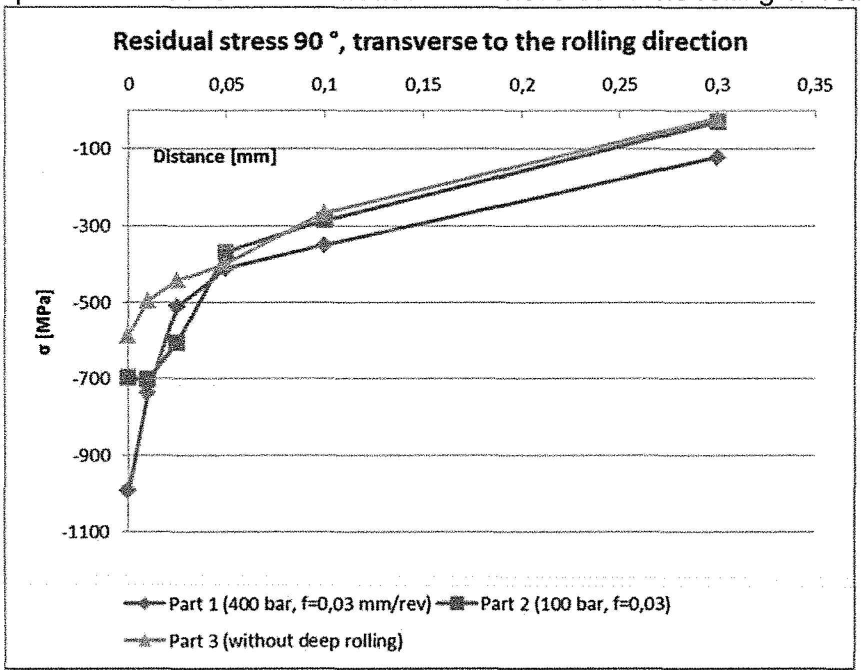
Discussion and Conclusions

After reaming, compressive residual stresses already existed in the surface layer as expected. By deep rolling it was possible to increase the values for the compresses residual stresses. Also, the increase in the deep rolling force led to a deeper penetration. Additionally, one can see that the values for compressive residual stresses measured transverse to the rolling direction are higher than those measured in longitudinal direction. This is due the material flow during the rolling treatment, and the associated formation of compressive residual stresses.
The half-widths show an increase in the initial hardness by deep rolling in the material.

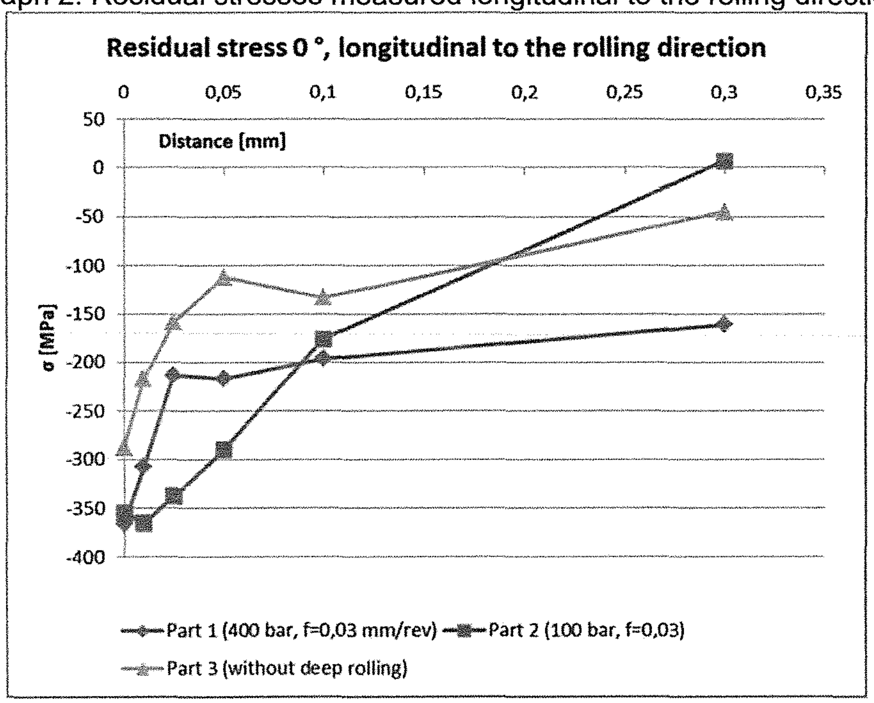
In summary, the parts with bore holes of 3 mm and their characteristics could be improved by deep rolling. Therefore a new tool has been developed to be able to process such small diameters. By using the new developed tool for deep rolling, it is possible to improve the lifetime of components due to smoothing the surface, increasing the hardness and the induction of compressive residual stresses. Components with such a small diameter will be able to be processed by deep rolling to improve their fatigue behavior.

So it is possible in the future, to deep roll small holes in all industries. Bore holes in crankshafts or other components of the automotive industry, aviation components or medical devices would be possible applications.

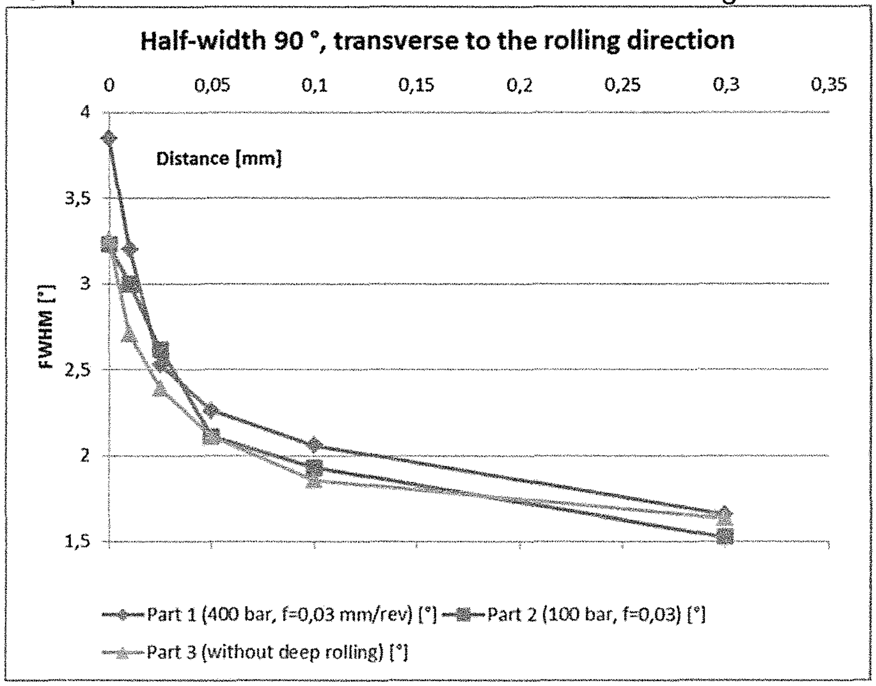
Graph 1: Residual stresses measured transverse to the rolling direction



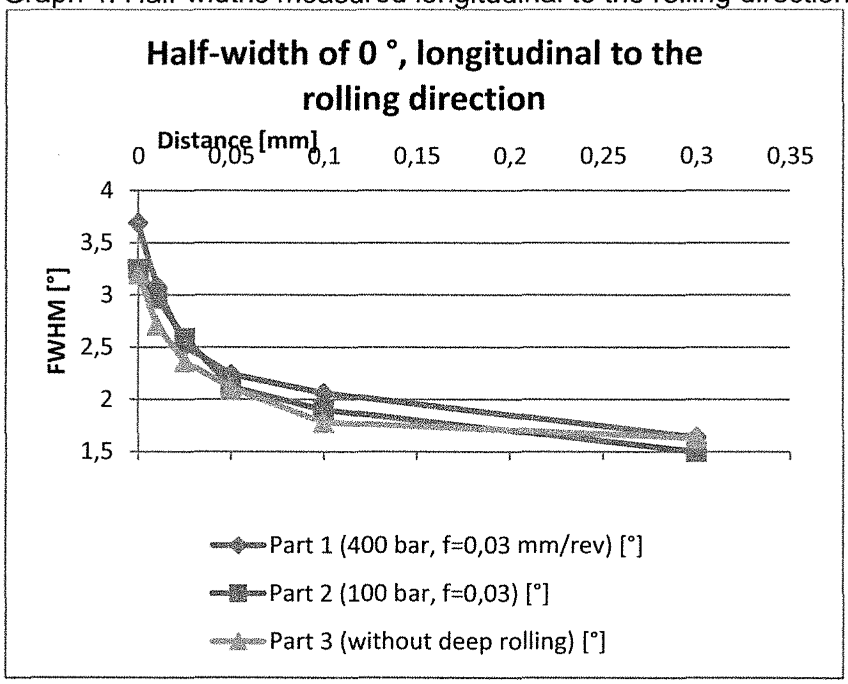
Graph 2: Residual stresses measured longitudinal to the rolling direction



Graph 3: Half-widths measured transverse to the rolling direction



Graph 4: Half-widths measured longitudinal to the rolling direction



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