Influence of Shot Peening on Stress Corrosion Cracking in Stainless Steel

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1 Abstract

Shot Peening is usually considered as a sensible method to prevent cracking related to fatigue or stress corrosion. In this paper, I will present the results of static stress corrosion tests of three austenitic materials. The specimens for tensile testing were made from the materials 1.4571 (X6CrNiTi17-12-2), 1.4541 (X6CrNiTi18-10) and 1.4462 (X2CrNiMoN22-5-3).

The different shot peening parameters were selected by the Peenstress^{sm} Software. The calculated and measured residual stress profiles are very close.

2 Introduction

Controlled shot peening is an established process that is used to increase the resistance of metal parts to fatigue failure in a great variety of industries, including aircraft, aerospace, automobile, heavy equipment, power generation, petrochemical, etc. The residual compressive stresses introduced by shot peening have a major beneficial effect not only upon metal fatigue but upon all

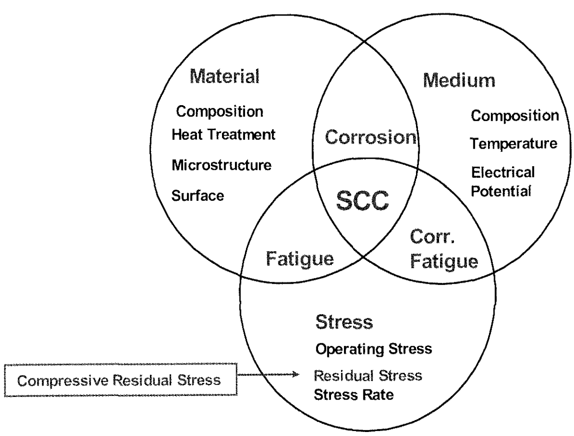


Figure 1: Influence of critical states on material failures

the tensile stress related modes of failures such as stress corrosion cracking, corrosion fatigue, thermal fatigue and fretting fatigue. To these can be added the purely mechanical effects of a peened surface that can reduce galling, improve lubricity, close porosity, increase sealing properties, and even form parts or correct their shape.

It is an established fact that stress corrosion cracking (SCC) only occurs in the presence of a critical state in the working material caused by environment conditions and by sufficiently high tensile stress (Fig. 1). The residual compressive stresses induced by the shot peening procedure will have a positive effect on fatigue, on stress corrosion cracking resulting from any oscillation and on tensile crack corrosion in the components.

In chemical plants it is not possible to exert influence on the medium and thereby prevent stress corrosion cracking. For this reason the materials and the distribution of residual stresses were varied in the tests conducted.

3 Materials and Experimental Procedures

Three typical materials, all used in chemical plants, were selected for the tests under laboratory conditions.

1.4571 X6CrNiTi17-12-2
1.4541 X6CrNiTi18-10
1.4462 X2CrNiMoN22-5-3

From the chosen materials, tensile specimens (proportional test bars) were made for the stress corrosion cracking tests. An unpeened specimen of each material was solution heated to reach a uniform starting state. The remaining specimens were then peened in line with three different shot peening parameters.

The shot peening parameters were selected and optimised with the assistance of the Peenstress^{sm} Software.

Figure 2 shows the relationship between the basic shot peening parameters and the distribution of residual stress [Source: B. Scholtes DGM 1990].

The proportional test bars selected were processed in automated equipment and under full production conditions on the Peenamatic shot peening systems.

The shot peening medium for all of the specimens was Stainless Steel Cut Wire (SSCW), size 0.8 mm, material 1.4310, hardness 610–670 HV1. The intensities were 5 A, 12 A and 20 A. The degree of coverage was uniform at 100 % for all specimens, and this was controlled by means of the PEENSCAN procedure.

The following diagrams indicate the calculated distributions of the residual stress of the various materials. The residual stress values were measured with the hole drilling method and they are denoted in each case by a small rectangle.

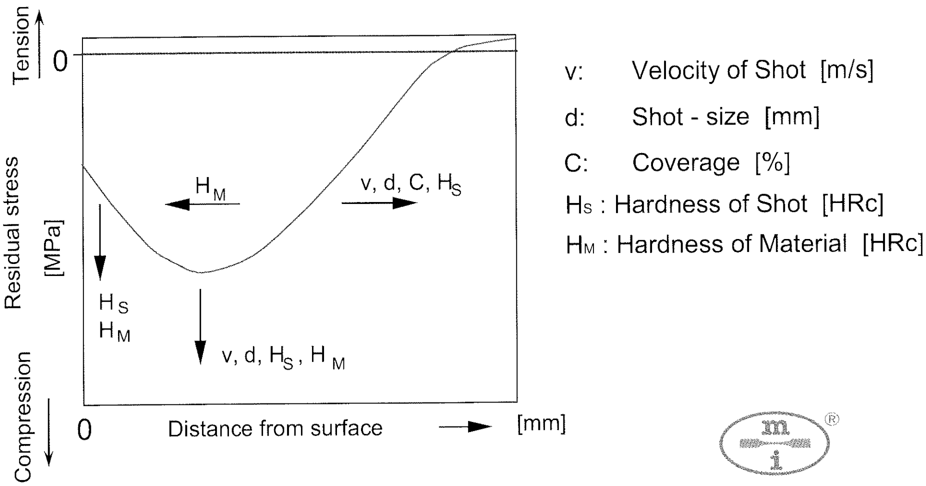


Figure 2: Shot Peening Parameter vs. Residual Stress Distribution

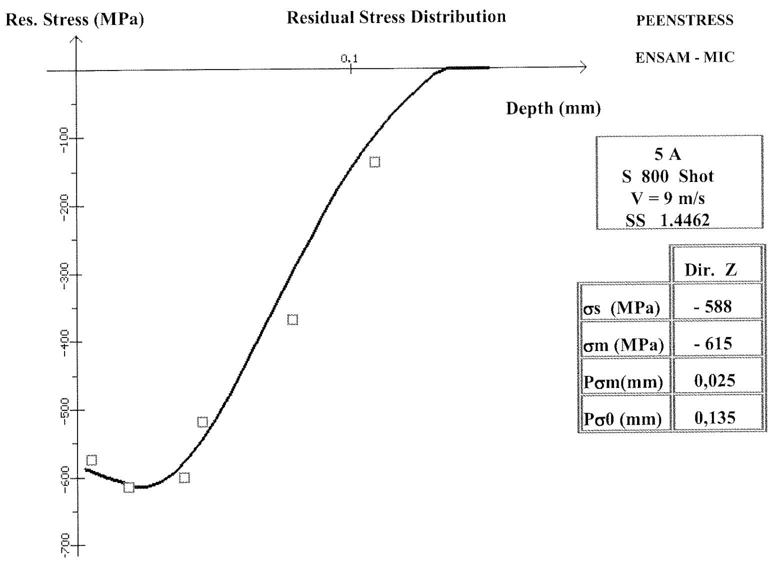


Figure 3: Residual stress distribution in shot peened 1.4462

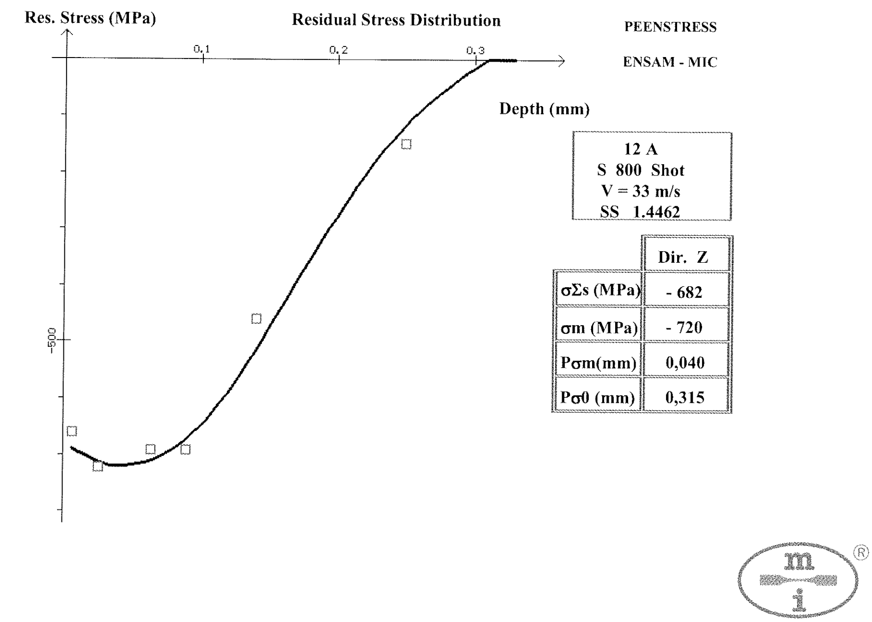


Figure 4: Residual stress distribution in shot peened 1.4462

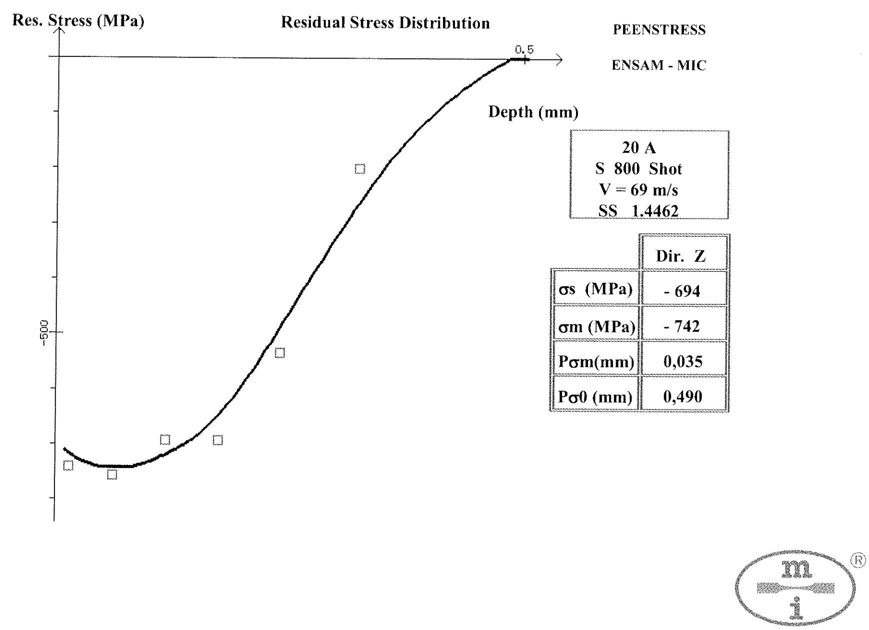
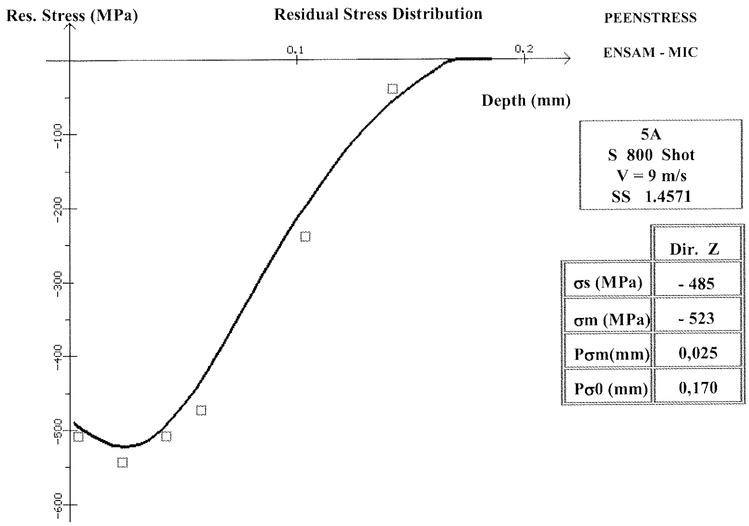
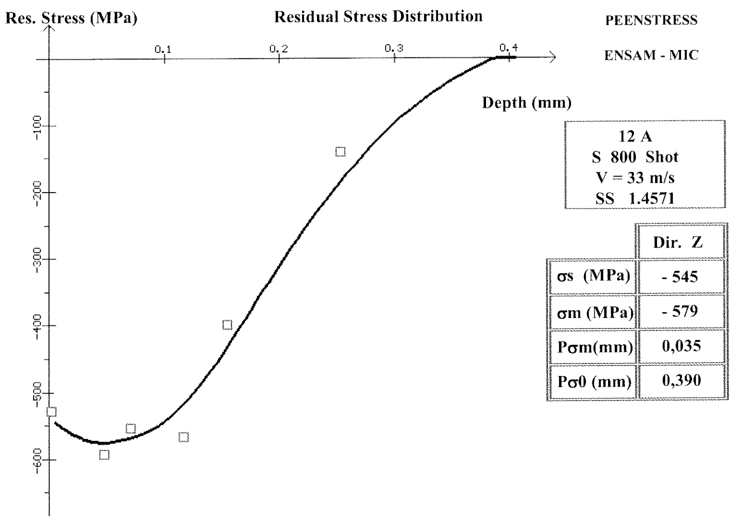


Figure 5: Residual stress distribution in shot peened 1.4462



	Dir. Z
σs (MPa)	- 485
σm (MPa)	- 523
Pσm(mm)	0,025
Pσ0 (mm)	0,170

Figure 6: Residual stress distribution in shot peened 1.4571



	Dir. Z
σs (MPa)	- 545
σm (MPa)	- 579
Pσm(mm)	0,035
Pσ0 (mm)	0,390

Figure 7: Residual stress distribution in shot peened 1.4571

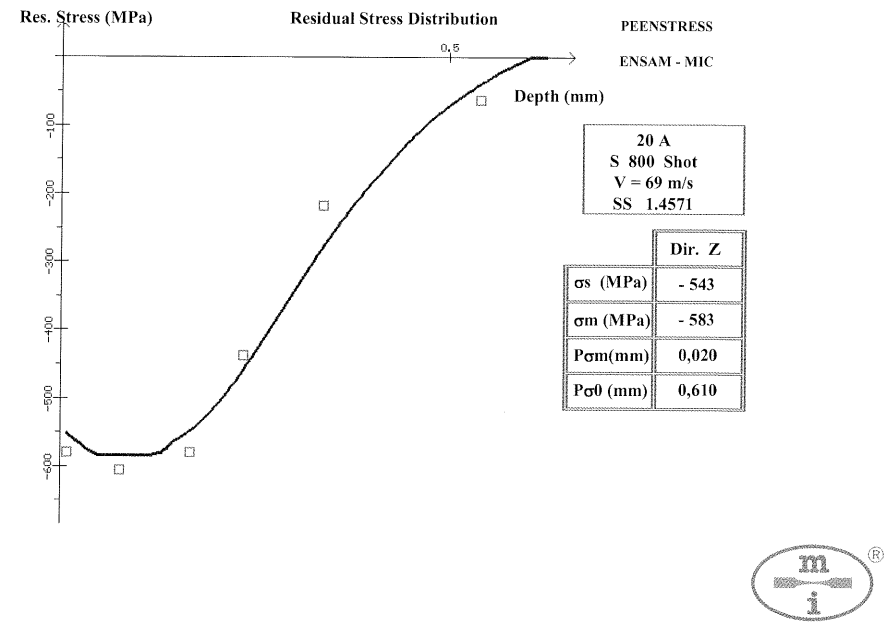


Figure 8: Residual stress distribution in shot peened 1.4571

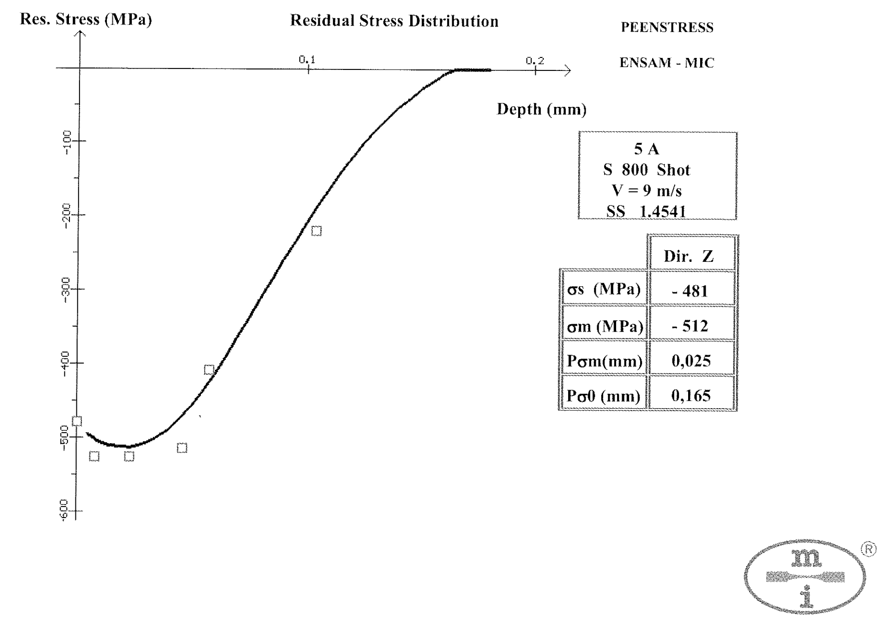


Figure 9: Residual stress distribution in shot peened 1.4541

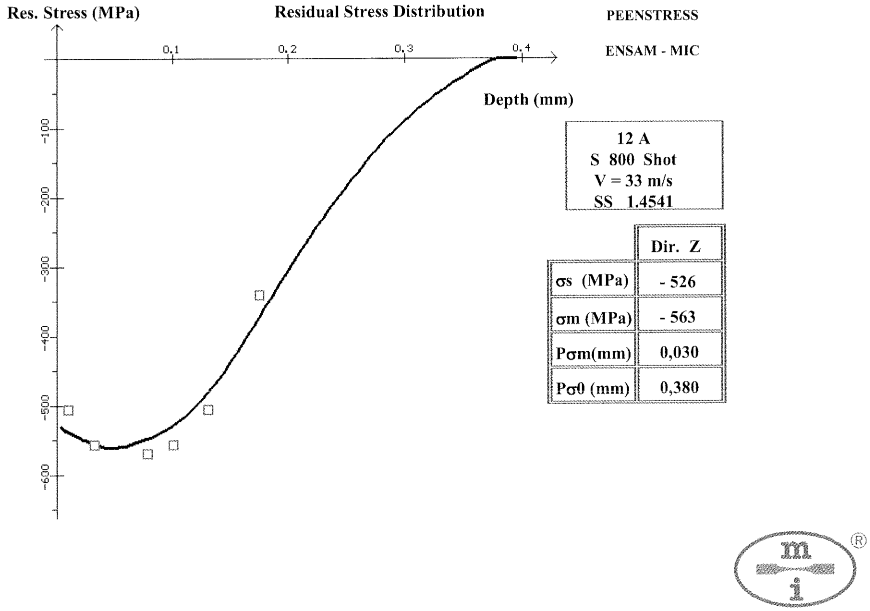


Figure 10: Residual stress distribution in shot peened 1.4541

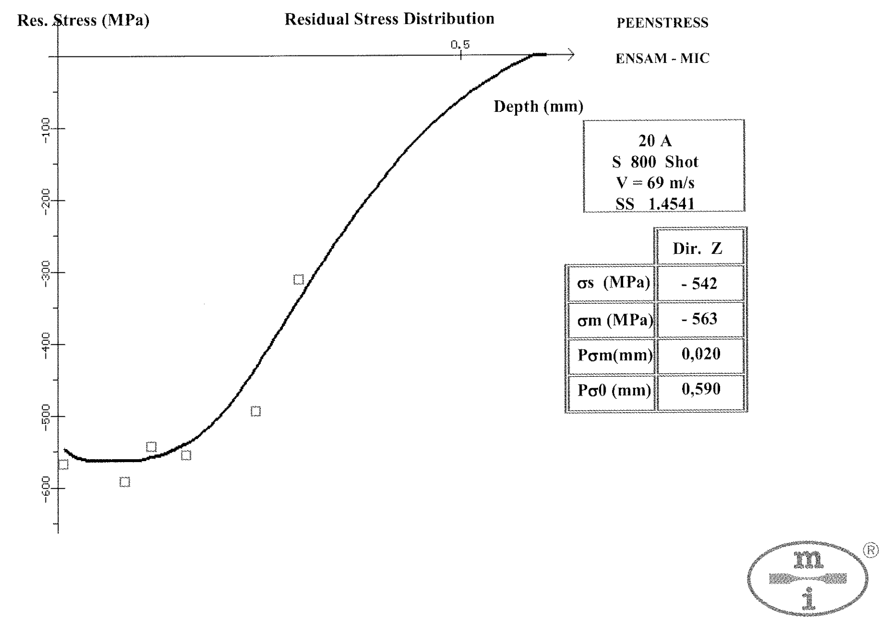


Figure 11: Residual stress distribution in shot peened 1.4541

The proportional test bars were fixed firmly in a holding device and tested statically for tensile strength. In total, four loading conditions at 50 %, 70 %, 80 % and 90 % of the yield stress (σ_y) of the respective materials were applied. The specimens were exposed to a 42 % $MgCl_2$ solution at a constant temperature of 145 °C.

4 Results and Discussion

Table 1 displays the exposure times elapsed until the onset of stress corrosion cracking. Due to the limited time available for the tests, not all permutations were tested. The tests were aborted after an exposure period in excess of 1,000 hours without any findings.

Table 1: Exposure times elapsed until the onset of stress corrosion cracking

Material	Shot Peening Parameters	Tensile Stress	0.5 σ_y	0.7 σ_y	0.8 σ_y	0.9 σ_y
1.4541	not peened		11h	5 h	–	3.2 h
		SSCW 0.8, 5A, 100 %	–	–	–	–
		SSCW 0.8, 12A, 100 %	–	–	–	–
		SSCW 0.8, 20A, 100 %	–	>1000 h	–	>1000 h
1.4571	not peened		17h	11.3 h	–	7.5 h
		SSCW 0.8, 5A, 100 %	–	–	–	–
		SSCW 0.8, 12A, 100 %	–	>1000 h	–	>1000 h
		SSCW 0.8, 20A, 100 %	–	>1000 h	–	>1000 h
1.4462	not peened		5.3h	3.3 h	–	1.3 h
		SSCW 0.8, 5A, 100 %	–	–	–	–
		SSCW 0.8, 12A, 100 %	–	>1000 h	>1000h	2 h
		SSCW 0.8, 20A, 100 %	–	>1000 h	>1000h	5.3 h
1.4529	not peened		–	500 h	–	37 h

The results given here demonstrate clearly that controlled shot peening the materials significantly increases their resistance to stress corrosion cracking in all three cases.

On inspection of the exposure times of the unpeened specimens it is noted that the material 1.4462 has the lowest resistance to stress corrosion cracking. The application of controlled shot peening at a stress of 0.7 σ_y, the exposure time can be increased from 3.3 hours to over 1,000 hours. At a stress of 0.9 σ_y, the improvement is not so significant.

The results for the material 1.4529 in a peened state are not yet available. The exposure times of 500 hours and of 37 hours permit the conclusion that the shot peened version will generate also no findings.

Even under high static loads, the materials 1.4541 and 1.4571 display a marked improvement against stress corrosion cracking. Because of the high testing times required only a few alternatives were investigated. Not even under high static loads did any damage occur, therefore, it may be assumed that no premature damage needs to be anticipated at a reduced load earlier stage.

The application of controlled shot peening acquires special importance in the context of the production costs.

The production costs for a 5,000 litre storage tank made of the material 1.4541 and including the cost of shot peening would be approximately EUR 48,000. In case of making it from the material 1.4571, the production costs including shot peening would amount to EUR 50,000. The application of the material 1.4462 would increase the production costs to EUR 90,000 without including controlled shot peening.

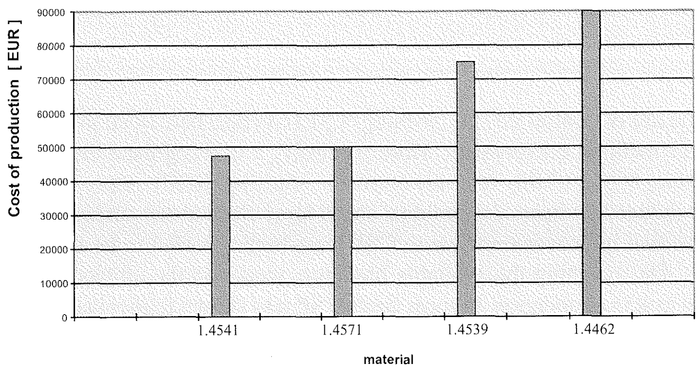


Figure 12: Comparison of material costs for a 5000 liter tank

5 Conclusions

- Up to now tests have only been completed under static load.
- In plant construction most components are under dynamic stress. In the future tests for corrosion fatigue will be carried out.
- On the basis of the results obtained the findings will be put into practice.
- The investigation into the production costs of a 5,000 litre storage tank revealed significant differences. For producing the tank from material 1.4541 or 1.4571 the cost for the controlled local shot peening at the site is already included.
- Controlled shot peening will significantly increase the resistance to stress corrosion cracking. Earlier research confirms the above findings in respect of ferritic base materials and in NH_3 media.
- On the basis of the present results less expensive materials may be used in plant the construction or in chemical plant without impairing the resistance to corrosion.