Improvement to the Fatigue Strength of Drop-forged Specimens by Airless Blast Cleaning

K. H. Kloos, B. Kaiser, Th. Oppermann, TH Darmstadt, Institut für Werkstoffkunde, Darmstadt, FRG

Introduction

Drop-forged components are usually airlessly blast cleaned after heat treatment in order to remove the oxide scales. It has been shown in many investigations /1, 2, 3/ that this type of treatment also offsets the negative influence of decarburization because it causes strain hardening and introduces residual compressive stresses. The interaction between the shot and the structure of the oxide scales is comprehensively investigated in /4/.
The results below were obtained during "Increasing the Fatigue Strength of Drop-forged Components by Means of a Defined Peening Treatment" research project. The objective of this work was first to carry out an investigation into the influence of the type of shot, the shot hardness, the peening time and the shot size on the bending fatigue behaviour (R = 0) of the material Ck 45 V ($\bar{R}_m$ = 813 N/mm²). The optimum peening conditions thus found were then applied to other typical forge alloys (Fig. 1) after usual heat treatments (Fig. 2). The peening was applied to the decarburized surfaces with oxide scales which typically appear after forging and the various heat treatments.

	$\bar{R}_{p0,2}, \bar{R}_{eH}$	$\bar{R}_m$	$\bar{A}_5$	$\bar{Z}$
	N/mm²	N/mm²	%	%
Ck 45 V	637	813	22	64
Ck 45 VS	650	835	18	54
Ck 45 BY	428	770	19	40
49 MnVS 3 BY	432	817	17	36
42 CrMo 4	1021	1107	15	56

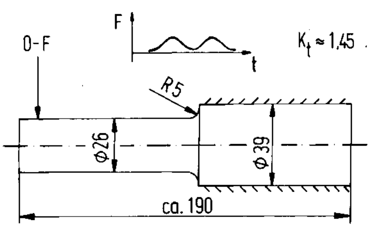


Fig. 1: Specimen geometry and materials

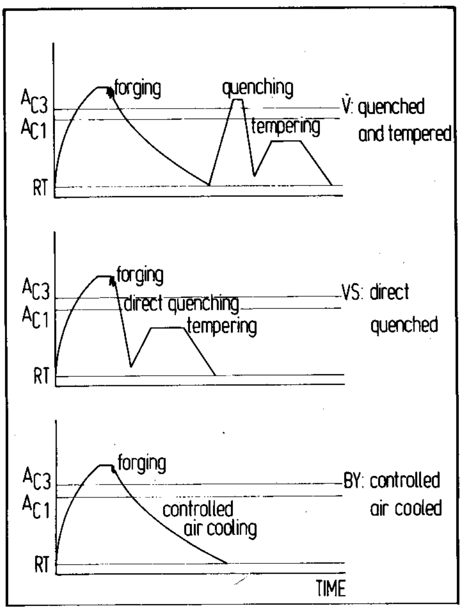


Fig. 2: Heat treatments

Results for Ck 45 V peened in different ways

The influence of the above airless blast cleaning parameters on the probability of survival $P_{ü} = 1 - \frac{\text{Number of fractures}}{\text{Number of specimens}}$ is shown in Fig. 3 (approximately 160 individual tests). All the types of shot used indicate a tendency for the probability of survival to increase with decreasing shot size. Maxima of the probability of survival were obtained by some peening conditiones with a coverage between 4 and 7.

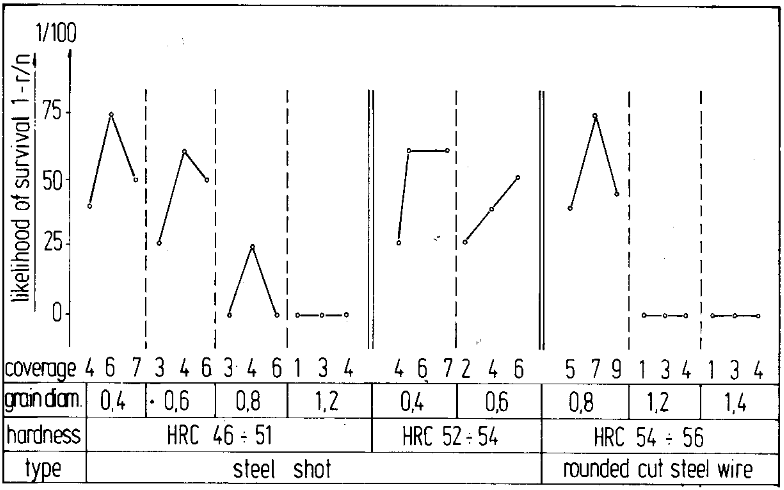


Fig. 3: Influence of different airless blast cleaning parameters on probability of survival (1- r/n) in the case of Ck 45 V, $\bar{R}_m$ = 813 N/mm², limiting number of cycles $N_G = 2 \cdot 10^6$ (R = 0, $\sigma_{nominal}$ = 530 N/mm²)

The influence of the peening parameters used in Fig. 3 on the surface roughness (R_{tmax}, R_{ZDIN}) is shown in Fig. 4. Since the surface parameter R_{tmax} always follows the mean surface roughness R_{ZDIN}, only the latter is considered below. Surface roughnesses between 20 µm and 53 µm are found as a consequence of a defined airless blast cleaning treatment. The surface roughness generated by various peening conditions are given in Table 1. A variance analysis, using the U-test by Wilcoxon, Mann and Whitney (95 % confidence level) /5/ confirms the classification employed.

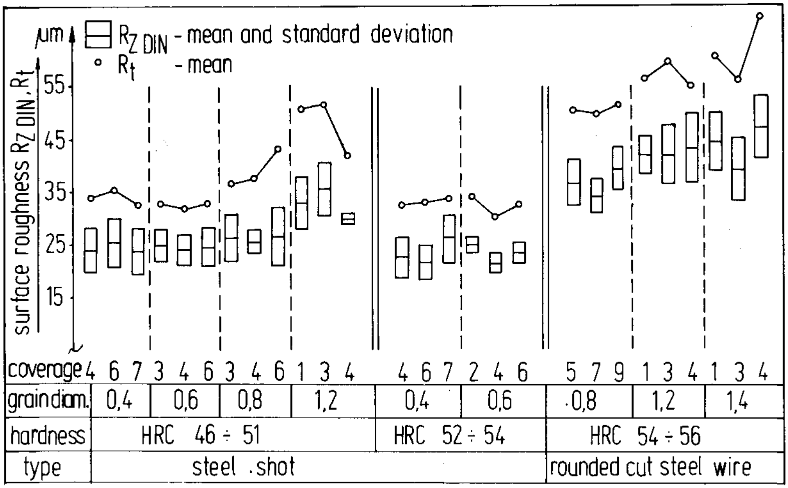


Fig. 4: Influence of different airless blast cleaning parameters on surface roughness R_{ZDIN} and R_{tmax} in the case of Ck 45 V, $\overline{R}_m$ = 813 N/mm²

Type	Hardness HRC	Shot diameter mm	Coverage	R_{ZDIN} ± standard deviation µm
Steel shot	46 - 51	0.4 0.6 0.8	4 - 7 3 - 6 3 - 6	18 - 31
Steel shot	52 - 54	0.4 0.6	4 - 7 2 - 6	
Steel shot	46 - 51	1.2	1 - 4	29 - 41
Rounded cut steel wire	54 - 56	0.8 1.2 1.4	5 - 9 1 - 4 1 - 4	31 - 53

Table 1: Influence of the airless blast cleaning parameters examined on R_{ZDIN} in the case of Ck 45 V, $\overline{R}_m$ = 813 N/mm²

Apart form the surface roughness, the hardness and residual stress distribution are the main factors determine the fatigue limit. The hardness and residual stress distribution caused by differently defined airless blast cleaning treatments are shown in Fig. 5. As far as the hardness profile is concerned the decrease in hardness due to the decarburization of the external zone can be fully compensated by the peening variants investigated here; the surface

hardness can be displaced to higher values up to a depth of about 0.2 mm by using a larger nominal shot diameter.
The influence of different peening conditions (particularly the size of the shot) on the residual stresses may be explained by the Hertzian theory, fully described in /6/. If the Hertzian stress is sufficiently high, the maximum shear stress occuring below the surface can exceed the yield strength and a residual compressive stress appears. The magnitude of the Hertzian stress depends mainly on the ratio of the force exerted by the shot on the material to be peened and the diameter of the residual plastic identation. The residual stress profiles (1st order, measured by X-ray procedure) determined during the present investigation show that the residual stress maximum moves towards the surface with decreasing shot diameter and the zone subject to residual stresses becomes thinner. Results with a similar tendency are also reported in /6/ and /7/.

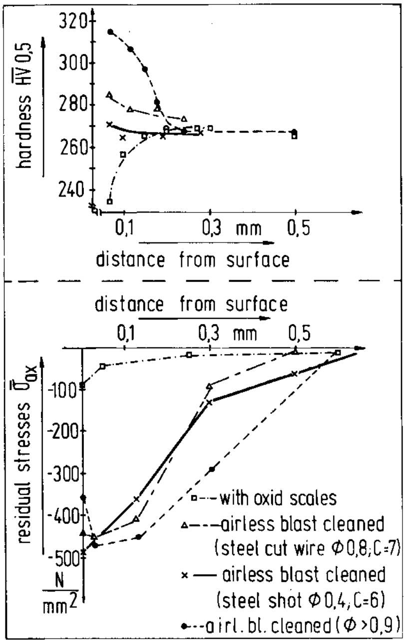
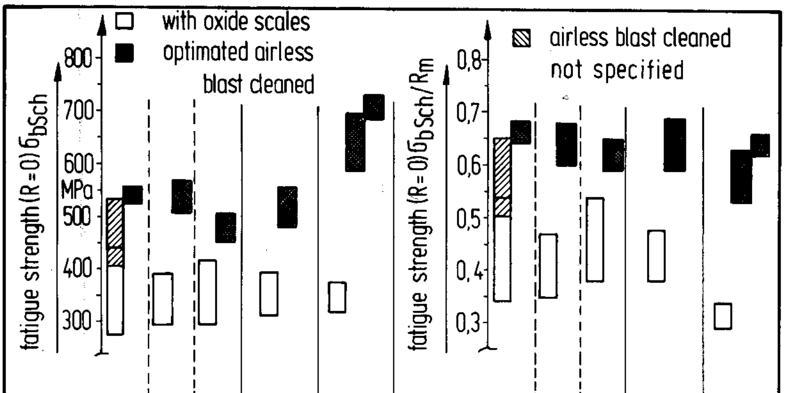


Fig. 5: Influence of different airless blast cleaning parameters on hardness and residual stresses in the case of Ck 45 V ($\bar{R}_m$ = 813 N/mm²)

The relationship between the peening conditions and the survival probability shown in Fig. 3 indicates that the two peening treatments steel shot (HRC 46 - 51, shot diameter 0.4 mm and a coverage of 6) and rounded cut steel wire (HRC 54 - 56, shot diameter 0.8 mm and a coverage of 7) give the best fatigue results. Since the surfaces treated with small shot are more difficult to assess using the magnaflux test usual in the forging industry, the other forging alloys (Fig. 1) were subjected to peening treatment using rounded cut steel wire (grain diameter 0.8 mm and a coverage of 7).

Fatigue strengths of all the specimens examined

The fatigue strengths of the materials treated with rounded cut steel wire (HRC 54 - 56, shot diameter 0.8 mm and a coverage of 7) are shown in Fig. 6.
The limiting fatigue strength σ_{bSch} is about 350 N/mm² in the case of the unpeened materials (decarburized and covered with oxide scales) - independent of the particular heat treatment (V, VS, BY) and tensile strength (R_m between 770 and 1100 N/mm²) -. The variation T = σ_{bSch} 90 %/ σ_{bSch} 10 % is between 1.2 and 1.6. An optimised, and hence defined, airless blast cleaning treatment reduces the variation to values between 1.1 and 1.2. The increase in the bending fatigue strength, relative to the decarburized unpeened variants (with oxide scales) (50 % fracture probability), is between 50 % and 110 % in the case of quenched and tempered materials and between 30 % and 60 % in the case of the controlled air cooled materials. The refered bending fatigue strength σ_{bSch} / R_m is between 0.63 and 0.66 in the case of the optimally peened materials - independent of the heat treatment (V, VS, BY) -. The influence of a not defined airless blast cleaning treatment - carried out by five forging plants - on the fatigue behaviour of Ck 45 V is also shown in Fig. 6. Without controlling the blast cleaning parameters the fatigue strength of these specimens may either be near the not peened or near the optimated airless blast cleaned specimens.
The variance of the unpeened 42 CrMo 4 V shows that a defined peening treatment not always decreases the variance. The variance depends on the homogeneousness of the residual stresses the hardness in the surface zone and the surface roughness.



tens.str/MPa	813	835	770	817	1107		813	835	770	817	1107
heat treatm.	V	VS	BY	BY	V		V	VS	BY	BY	V
material	Ck45			49MnVS3	42CrMo4		Ck45			49MnVS3	42CrMo4

Fig. 6: Fatigue strengths (R = 0) of $P_{B90\ \%}$ and $P_{B10\ \%}$ by using the arcsin p transformation (25 - 30 specimens/variant) $N_G = 2 \cdot 10^6$

In the case of the material 42 CrMo 4 V, the maximum of the fatigue resistance was not obtained with rounded cut steel wire but was obtained with steel shot (HRC 46 - 51, shot diameter 0.4 mm and a coverage of 6). This may be due to the smaller peak-to-valley heights produced by steel shot and the higher notch sensitivity suggested for the less tempered (R_m = 1100 N/mm²) material 42 CrMo 4 V.

The fatigue behaviour in the low finite life fatigue range and in the range of medium to low fracture probability is shown in Fig. 7. The scatter bands indicated by * in the S-N curves are linearly extrapolated or interpolated values of the experimentally determined Woehler curves of the particular materials. In the case of a load corresponding to a bending stress without notch effect of 0.77 · R_m of the particular material, airless blast cleaning treatment produces no increase in the number of cycles to failure - except for the material 42 CrMo 4 V. If the load is reduced to 0.63 · R_m, the cycles to failure of the unpeened variants are between 30.000 and 300.000, whereas the specimens subjected to optimum airless blast cleaning exceeded the limiting number of cycles of 2.000.000. Since it is known from the literature that an increase in the number of cycles to failure can be achieved by peening, the result found here is attributed to the relatively small depth effected by the residual compressive stress. The fact that airless blast cleaning treatment also produces a marked increase in the number of cycles to failure in the finite life fatigue area only in case of 42 CrMo 4 V may be explained by taking into account the residual stress stability of the material.

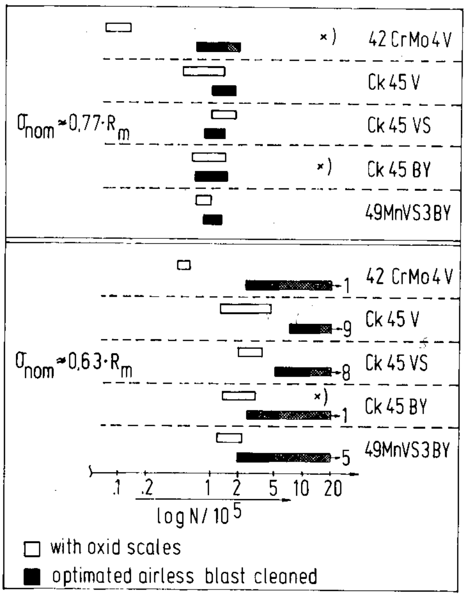


Fig. 7: Influence of an airless blast cleaning process on the fatigue behaviour of different forge alloys (R = 0)

The work was supported by the "Arbeitsgemeinschaft Industrieller Forschungsvereinigungen" and by the "Gesellschaft für Stahlverformung" and this opportunity is taken to thank them for providing the necessary funds. Also many thanks to the members of the "Arbeitskreis Dauerschwingfestigkeit im Industrieverband der Deutschen Schmieden (IDS)" for their competent support during the whole investigation. This work is a part of a Ph. D. theses of Th. Oppermann to be published.

References

(1) P. Herbst: Fortschr.-Ber. VDI-Z Reihe 5 Nr. 75, VDI-Verlag GmbH Düsseldorf, 1983.
(2) B. Knolle: Dissertation TU Hannover, 1978.
(3) W. Bender: AIF Transfervorhaben Nr. T 62, TU Hannover, 1981.
(4) H. Lepand: "Herstellung von Stahldraht" Teil 1, Verlag Stahleisen mbH, Düsseldorf, 1969, Herausgegeben vom Verein Deutscher Eisenhüttenleute.
(5) L. Sachs: "Angewandte Statistik", Springer-Verlag Berlin Heidelberg New York, 1978.
(6) H. Wohlfahrt: Berichtsband zur Tagung der Deutschen Gesellschaft für Metallkunde, Karlsruhe, 1983.
(7) M. P. Müller, C. Wüthrich, M. Roth: Material und Technik Nr. 2, 1985.