1

Shot peening and its applications
Grenaillage et ses applications
Kugelstrahlen und seine Anwendungen

SHOT PEENING,
A NIKU-LARI

H Fuchs

This fine comprehensive paper shows many data on shot peening effects in relation to the peening intensity. It would be very desirable to adopt a uniform nomenclature for intensity.

The paper uses the following:

- Arc height in mm (Figures 1, 5, 14)
- Numbers like "56A2" (Figures 2, 6, 7, 9, 11)
- A number "F 0,30 N" (page 21)

As the Almen intensity and its designation are well defined in the SAE standard J 442 (1982) and have been widely used for more than 25 years, it would seem best not to introduce other units which can only lead to confusion between "20" as 0.20 mm and "20" as 0.020 inches.

The Almen intensity is a number obtained in a standardized manner, like Brinell hardness. It need not be given in millimeters or inches. Assumming that for convenience in continental Europe one prefers dial gauges reading in increments of 0.01 mm, it is easy to convert these to Almen intensities by noting that 0.10 mm arc height on an A-strip corresponds to 4A, 0.20 mm to 8A etc.

A Niku-Lari

The SAE-j442 Standard is an American National and not an International Standard. There are some other National Standards in other countries.

F0.30N corresponds to the French Standard and means 0.30 mm arc heights measured on a Almen specimen type N. 56A2 or 56A corresponds to the internal standards of many companies in Europe and Asia, and means 0.56 mm arc-heights measured on a Almen specimen type-A.

To prevent all misunderstandings I think it is necessary to create a real International standard on shot-peening. I propose that the matter should be discussed in the next meeting of the International Scientific Committee.

Thank you very much for your conversion datas which are very useful for the proceedings.

H Fuchs

Page 18. The increase in fatigue limit from 132 to 165 looks good, but the increase in life seems rather low. Is there a typographical error? The degree of coverage "néant" is most mysterious. Does it mean there was no coverage at all? Or that it was not measured?

A Niku-Lari

The limited increase in fatigue life may be due to the fact that the shot peened area was only the flamed cut surface which has a very poor surface condition. In this case shot-peening does in fact increase the fatigue life, but one cannot expect any miracle from it. Shot peening cannot cancel manufacturing defects.

HISTORY OF SHOT PEENING,
P E CARY

H Fuchs

It may be useful to add a few words about the origins and early development of industrial shot peening.

Although the earliest publication (Foeppl, 1929) and the earliest patent application (Vorwerk, 1934) were found in the German literature, it seems that the process first was applied in production and developed in the United States, without benefit of the German work.

Bush, Almen, Danse and Heiss (1962) recall that about 1928 the service life of valve springs was a subject of concern. Various methods of cleaning were tried. Danse at Cadillac and Heiss at Buick observed that springs cleaned by shot blasting were clearly superior. A change request by C.A. Chayne of Buick, dated 12-3-30, reads in part:

> "Note added: Shot blast with steel shot of 0.30 or less diameter.
>
> Cancel note: Wire brush springs all over to remove all abrasive.
>
> Reason for change: To clean springs thoroughly – manufacturer's request."

The process was used in production, but the reasons for its success were not understood. Zimmerli (1940a) reported on these early developments, from the spring makers viewpoint. In a summary of this paper (1940b) he starts by saying, "Shot blasting has done more to increase fatigue life of our small springs than any of the alloy steels ever used."

J.O. Almen, inventor of engines, transmissions, and many other devices, then devoted himself to the investigation of shot peening. He told me that he changed from inventing mechanical devices to the study of fatigue life improvement because he was tired of having his designs second-guessed by administrators. He soon proclaimed that residual stresses (self-stresses) were the cause of the improvement, that stresses could not be calculated from loads and geometry alone, and that fatigue cracks would not propagate unless tensile stresses were present. (Almen, 1951).

During the war, 1941 to 1945, shot peening spread from the automobile industry to the aircraft industry and others, largely through the missionary work of Almen whose efforts were supported by a government grant. He started the SAE committee on shot peening in 1943 and was its guiding spirit. In 1944 John Straub, one of Almen's assistants, transferred from General Motors to Wheelabrator Corporation to work on using their machines for shot peening applications.

Almen's views were unorthodox at the time, and strongly resisted by some academics. But they prevailed and were eventually legitimized through the development of fracture mechanics.

By 1950, twenty years after its beginnings, shot peening was well accepted and discussed in engineering handbooks. (Almen 1950, Horger 1964).

Peen forming was developed about 1950 when Lockheed designed the Super-Constellation, using skins on which the stiffening stringers were integral parts of the skin, machined from a thick plate of aluminum. Forming such skins in presses is not practical. Borger (1955) conceived the idea of peen forming and Metal Improvement Company designed the machine and developed the process to peen form the wing skins for Lockheed.

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EFFECT OF SHOT PEENING ON THE FATIGUE STRENGTH OF SMALL SPRING WIRE AND COIL SPRINGS,
S HIROSE

R G Slingsby

What type of shot peening equipment was used for the experiments? How were the Almen test strips shot peened to represent the springs?

S Hirose

The peening equipment used for the experiment was wheel type (Type SCB-2B, manufactured by Sinto Works, Japan, for various tests). The capacity of projected weight of shot is 100kg/min. The test pieces were put into a cylindrical coarse cage made of strong steel wire netting, which was laid on two parallel rotating rollers and revolved with a rate of 6 rpm., and shot peened.

Three strip holders were put into the same cage without test pieces and the arc-height was measured. Accordingly, these values are not those of arc-height with respect to coil springs, but it would rather better think as that the peening conditions are confirmed and the steady state of the processing is judged by these values of arc-height. In this report, therefore, arc-height is merely utilized to show an intensity of shot peening processing.

The measurement of arc-height for outer and inner surface of large real coil spring had ever been done. Two local parts of the spring wire was cut away and welded test strip holders in situ to measure two values of arc-height, mentioned above. Then, the spring was shot peened as usual. On the other hand, the author had found by simulation method*which harnesses the similarities between stream of shot and light, that the ratio of the arc-height for the inner side to the one for the outer side is governed almost by the ratio of pitch p to wire diameter d, namely p/d, and it increases exponentially as exposure time passes. It was also found that the results coincide with the experimental ones to a great extent..

The value of arc-height in this report might be referred to that of coil spring by applying the simulation method.

M C Sharme

How do you shot peen closed coil springs of 0.8 mm to 4.0 mm diameter by wheel type process in respect to induce proper amount of residual stresses for inner and outer surface of the spring wire?

S Hirose

The test coil springs used in the experiment were not closed ones, so the inner

*S HIROSE: "Simulation of shot peening coil springs", Rep. of the Casting Res. Lab., Waseda Univ., No. 26, pp. 11-19 (1975) November.

surface of the spring was peened by shots which passed through gaps between coil spring wire. If closed coil springs were shot peened, suitable opening between coil spring wire should be made by pulling both ends of coil spring with proper jigs. It may mean stress peening.

In order to induce adequate residual compressive stress for inner and outer surface of the spring wire, the values of arc-height for both sides should be proper ones. But, the values of arc-height used in this report do not coincide with the ones, above stated. Since the fatigue failure of coil spring starts at inner surface, it must be concentrated on the arc-height for inner surface. Then, the outer surface may be over peened. The author hopes that the relation of arc-height between inner and outer side will be stated in reference to question 2.

M C Sharme

How arc-height have been related from flat Almen strip to wire of the spring.

S Hirose

The correct answer to this question seems to be very difficult for the author. He wishes to introduce one experimental result and a simulation method with respect to this problem.

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VERBESSERUNG DER SCHMIEDESTUCKEIGENSCHAFFEN DÜRCH FESTIGKEITSSTRAHLEN

E DOEGE

A Niku-Lari

Wie haben sie die Bedekungsgrad Gemessen.

H Fuchs

Please define "Überdeckungsgrad" and explain how Ü=1 is measured.

E Doege

Der Überdeckungsgrad 1 ist erreicht, wenn 98% der zu strahlenden Oberfläche von Strahlmittel beaufschlagt worden ist. Die Bestimmung des Überdeckungsgrades erfolgte durch mikroskopisches Ausmessen. Bei Variation der Überdeckung über 98%

*S HIROSE: "Simulation of Shot Peening Coil Springs", Rep. of the Casting Res. Lab., Waseda Univ., No. 26. pp. 11-19 (1975) November.

hinaus wurde die Strahlzeit zur Definition herangezogen. Höhere Überdeckungsgrade sind ein Vielfaches der für eine 98%ige Überdeckung erforderlichen Strahlzeit.

W Manfred

Sie haben gezeigt, daß die Biegewechselfestigkeit vergüteter Schmiedestücke durch Kugelstrahlen zwischen Überdeckungsgrad 1 und 4 um etwa 10% ansteigt. Der Wert dieser Aussage wird aber erst erkennbar, wenn man ebenfalls angibt, wie sich die Streubreite der Biegewechselfestigkeitswerte ändert, da der Anwender vorwiegend an der unteren Grenze des Streubandes interessiert ist und, wie Sie gezeigt haben, sich auch die Rauhigkeit der Oberfläche ändert, die vermutlich einen Einfluß auf die Streubandbreite haben wird.

E Doege

Die Auswertung der Versuchsergebnisse der Biegewechselversuche hat gezeigt, daß die Streubreite der Wechselfestigkeitswerte mit steigendem Überdeckungsgrad zunächst abnimmt. Beim Überdeckungsgrad 6 wurde jedoch wiederum eine größere Streubreite festgestellt.

B Kaiser

1. Wurde auch das Gefüge im entkohlten Bereich untersucht (nur Kohlenstoffverarmung oder Ferritbildung in der Randschicht)?

2. Welche Wechselwirkungen von Randentkohlungstiefe und Kugelstrahlwirkung haben Sie hinsichtlich der Dauerhaltbarkeit beobachtet?

E Doege

1. Das Gefüge in der entkohlten Randzone wurde metallographisch untersucht. Bei den für die Untersuchung gewählten Randentkohlungstiefen von 0,2 und 0,4 mm wurde keine direkte Ferritschicht, sondern nur eine Kohlenstoffverarmung festgestellt.

2. Untersuchungen hinsichtlich der Dauerhaltbarkeit sind bisher im Hinblick auf die Kugelstrahlwirkung, d.h. in Abhängigkeit vom Überdeckungsgrad, durchgeführt worden. Es ist beabsichtigt, diese Untersuchungen auch in Abhängigkeit von der Randentkohlungstiefe durchzuführen, so daß Wechselwirkungen zwischen Entkohlungstiefe und Kugelstrahlwirkung auf die Dauerschwingfestigkeit ermittelt werden können.

E Rupp

Ist es überhaupt zu verantworten, zum Kugelstrahlen steel shot einzusetzen, wo wir doch im Lichtbild gesehen haben, dass dazu der Stahl ins Wasser gespritzt unddabgeschreckt wird, dabei zwangsläufig Spannungen unterworfen, die zu Rissen und Lunkern führen müssen, welche den grössten Teil der anfänglich runden Körner gleich beim ersten Schleuderrad – Durchgang kantig platzen lassen, was zu Kerben in den zu strahlenden Werkstücken führt, die unabwendbar einen optimalen Verfestigungseffekt verhindern müssen, weshalb die Firma Bosch, Stuttgart, in ihrer Kugelstrahl-Werknorm für ihre höchst-empfindlichen dünnen Ventilfedern die Verwendung niemals splitternden arrondierten Drahtkorns bindend vorschreibt.

E Doege

Für das Strahlen von Gesenkschmiedestücken werden sowohl Stahlschrot als auch Drahtkorn eingesetzt. Die von Ihnen geäußerten Befürchtungen beim Strahlen mit

Stahlschrot können nicht bestätigt werden, wie von uns durchgeführte Betriebsgemischuntersuchungen in verschiedenen Schmiedebetrieben gezeigt haben. Eine negative Auswirkung auf die Oberflächenfeingestalt durch das Strahlen mit Stahlschrot konnte bei den meist duktilen Schmiedewerkstoffen nicht festgestellt werden.

M Lazare

La plupart des conférences ou communications concernent des aciers alliés. Existent-ils des études sur l'influence du grenaillage sur les tenues en fatigue de pièces embouties en tôle à très faible carbone (qualité 1C). Nous avons obtenu de bons résultats (jusqu'à 60% d'augmentation du nombre de cycles) par grenaillage à la bille de verre dans les zones travaillant en sollicitations alternées.

2

Machines and materials
Matériaux et machines de grenaillage
Anlagen und Strahlmittel

J F Loersche

How can one measure intensity when peening small holes (less than ½")?

E J Hill

My own knowledge of shot peening inside holes is that it is a practical proposition down to ½" (12.7mm) diameter using a ported lance. In such cases the hole can be simulated in a test piece and a section machined away locally for the Almen strip and holder to be inserted. While this will not follow the curve of the hole, it does provide an accurate basis for comparison for repeatability purposes.

J Daly

Holes as small as 0.093" (2.3mm) are shot peened in production on jet engine and diesel engine components. Intensity is verified by the use of a "mini Almen strip".

M C Mead

Does the system for SNECMA has capacity to provide CIRCULAR interpolation to allow for continuous path contour peening on parts?

M Cardon

Yes. The system could have circular interpolation between 2 axes at the same time, this allowing continuous path contour of parts as found on jet engines. This is also intended to simplify the establishment of programs and it is not necessary to calculate the result of 2 axes measures. On our system with 3 axes, the important axes are vertical motion and horizontal swing. The 3rd axe is mostly an orientation axe for nozzles.

J M Leckner

Les analyses réalisées jusqu'à ce jour au niveau de la conception des salles de contrôle réfèrent toutes à des analyses statiques des caractéristiques physiques et spatiales des matériels. L'analyse dynamique, c'est-à-dire la prise en compte des informations issues de ces matériels et leurs traitements par l'homme pour en définir la signification discriminante par rapport à l'image initiale qu'il a du

système, n'y est par ailleurs peu souvent intégrée. Comment donc aménager des systèmes de contrôle, de régulation suffisamment adaptés aux hommes qui ont à les conduire?

M Cardon

Il est exact que jusqu'à maintenant les systèmes de contrôle utilisés dans le grenaillage de précontrainte n'ont pas souvent fait appel aux notions d'ergonomie.

Par contre, nous avons essayé de concevoir des systèmes destinés aux hommes qui ont à les conduire du point de vue de la capacité intellectuelle propre et du niveau de connaissance.

En remplacant des réglages ou des commandes manuelles par des systèmes à calculateur intégré permettant de réduire considérablement le nombre de commandes à utiliser pour obtenir les mises en service et la répétition d'un travail sur une machine, en permettant d'autre part un dialogue en clair réduit à des séries répétitives de questions pour lesquelles seules quelques réponses peuvent être rentrées et en indiquant également en clair sous une forme immédiatement intelligible toute anomalie de service, nous pensons avoir fait progresser les systèmes de contrôle pour le grenaillage de précontrainte.

Il reste à aménager les dispositions physiques du système de contrôle pour que la compréhension par l'opérateur soit essentiellement le transfert mental de mouvements physiquement visibles aux indications limitées et claires d'un écran vidéo indiquant lui-même les boutons, poussoirs, à utiliser pour influer sur la marche de la machine ou la réalisation d'un programme permanent.

G Mabille

Qu'est ce qu'on sait sur l'utilisation de la grenaille en Aluminium:

- précontrainte
- surfaces
- pollution
- mesure de la temperature d'impact.

M Cardon

En ce qui concerne cette question posée par Monsieur MABILLE, il ne s'agissait pas d'une question mais d'un exposé concernant les grenailles d'aluminium qu'ils fournissent. Aussi, je pense qu'il est mieux placé que moi pour exposer son point de vue.

G Mabille

Il nous paraissait nécessaire de poser cette question, compte tenu des différents exposés concernant la Précontrainte sur différents matériaux, mais aussi et en particulier sur des alliages d'Aluminium.

Or, il est apparu que dans l'assistance présente, rapporteurs ou congressistes, que ce produit déjà ancien était inconnu.

Notre intervention, nous l'espérons et le souhaitons suscitera une vive curiosité de la part des spécialistes présents à ce premier congres sur la Précontrainte.

En effet, l'utilisation de grenaille d'Aluminium permet d'obtenir des degrès d'intensité faible, avec une certaine régularité mais aussi et surtout d'utiliser des accélérateurs centrifuges "turbines" à vitesse variable.

D'autre part, les risques de fragmentation sont nuls et la pollution des surfaces est pratiquement impossible – Ces 3 éléments favorables doivent permettre un nouveau développement de la Précontrainte sur les alliages légers en particulier:

(1) intensité moyenne ou faible

(2) projection par turbine, voie sèche donc production intensive par machine de grande capacité

(3) pollution des surfaces inexistante
aucun risque de microfissures ou d'effet d'entaille,
couple électro chimique –

Mesure de la temperature a l'impact de la Grenaille.

Afin de rechercher des matériaux résistants à l'abrasion d'une part, et d'autre part de tenter de définir la concentration du niveau d'activité d'un flux de grain projeté, nous avions réalisé des jauges de mesure, réalisées dans des matériaux différents, alu – cuivre – acier – acier traité.

Ces jauges de forme cylindrique creuse, permettaient d'y adjoindre une thermistance raccordée à un appareil de lecture de température.

Ainsi nous avons pu observer dans un flux débit de 350 kg/mn des échauffements de l'ordre de 180^0 C. (poids de la jauge 50 grs) et ceci après 2 min. 15 sec.

Ces essais ont été pratiqués en 1971 et nous pensons que les moyens modernes actuels de mesure doivent permettre d'améliorer ces résultats.

3

Control of shot peening
Contrôle de grenaillage de precontrainte
Kontrole der Strahlbedingungen

GENERAL ASPECTS OF SHOT PEENING, CRITERIA OF PARAMETERS SELECTION,
T BURAKOWSKI & A NAKONIECZNY

H Fuchs

Formula 1 and Fig. 2 are taken from an SAE recommended practice which has now been revised to omit this formula and figure because they are not correct.

Experience shows that 100% coverage is obtained quite easily, not as a limit after infinite time. The situation is quite analogous to the coverage of the ground by leaves falling from a tree in autumn: The ground is soon covered completely.

The formula is approximately correct for low values of coverage. At high values it does not calculate the coverage, but the approximate probability of having achieved 100% coverage. If 90% coverage is obtained in 1 minute then after one more minute of the same treatment the probability of having achieved 100% coverage is 99% according to this formula, and after another minute it is 99.9%. If the experiment were repeated 1000 times, we would expect 100% coverage in 999 of the specimens and less than 100% on one specimen.

One can and does achieve 100% coverage. One can also obtain and specify 200% or 300% coverage, which would be quite impossible according to the obsolete formula.

IMPROVED METHODS OF SHOT PEENING CONTROL EXAMINES VARIABLES IN PRODUCTION PROCESS,
A M SANDERSON & R G SLINGSBY

Vanuxeem

I have noticed that your tests have been positioned to obtain a typical fracture located around 200,000 cycles with a stress frequency of 310 hz, that is a test length of about 11 minutes.

Have you, in these conditions, noticed the temperature reached by the item during the test?

If this temperature is much higher than that of the ambient, do not you fear that the test results will be influenced by this heat rise?

R G Slingsby

We have not attempted to accurately measure the temperature change during the test period but have some indication that the changes are not large. Even if the test specimen does attain a temperature above ambient it is considered that because we have deliberately chosen a stress range to cause failure in a relatively low test time and because all the tests are of limited duration, comparison of the results are valid.

R S Livesey

Accepting the limitations of the Almen test piece (e.g. it cannot be used as a direct stress correlation device), as a basic production control reference it is very effective. Also with bulk processing methods there must be some variations (if only slight) between parts in a batch. On these stated premises it is difficult to see how the authors test method, although ingenious, solves the stated limitations and problems of batch processing.

R G Slingsby

We have consistently observed very wide variations in Almen arc rise when several Almen test pieces (in pairs on backing blocks) have been processed together with a batch of work in a "tumblast" type machine. This variation being much greater than that obtained by processing several fatigue test pieces in a similar way. We conclude that because of shape and density differences the Almen specimens do not react in the mass in the same way as the springs or spring type test pieces.

It is not claimed that the method described can be applied in all cases as a substitute for the Almen test but consider that the fatigue test method correlates much more effectively to the variables of this type of bulk processing.

P Arnaud

Could we know the dispersion of Almen tests (fig. 1) which is probably related to the heterogenity of the peening that could lead to non significant results in fatigue tests.

R G Slingsby

The individual Almen arc heights recorded for the test series on which are illustrated by Fig. 1 were as follows:

PEENING TIME (MINUTES)	ALMEN ARC RISE (MM)			
	1.	2.	3.	4.
5	2.07	1.72	5.18	1.40
10	4.32	1.27	5.77	5.41
20	6.61	2.25	1.27	4.07
40	5.72	6.22	4.83	4.57

This shows the wide variation obtained when 4 Almen test pieces are placed together with a typical batch of springs and shot-peened in a "tumblast" type machine.

We are quite sure that the variations due to the machine are not this great, the fact that the variations in Almen results become less significant at 40 minutes strongly support our conclusions that the Almen test pieces do not tumble in the same way as the mass of work and only reach "saturation" after a relatively long period of time.

The Fatigue tests indicate that "saturation" is reached after 20 minutes shot-peening, this is generally confirmed by the whole experiment.

A NEW TYPE OF NOZZLE DEVELOPED TO STUDY THE EFFECT OF SHOT SIZE ON INTENSITY OF PEENING UNDER SPECIFIED . PEENING PARAMETERS,

M C SHARMA & A K JAIN

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The figs. 5 and 6 show a maximum for deflection of test ship. We think that the deflection increases continuously with the peening time, at least for usual periods of time. Are the operating conditions (strips or shot hardness ...) the reason for such a special behaviour.

M C Sharma

Yes the figure No. 5 and 6 shows the saturation curve of different shape as compared to the normal saturation curve, it is due to the property of the Almen strip material. The Almen strip materiai was of medium Carbon steel (hardness 50 R_B and thickness 1.7 mm.), and the hardness of 1.0 mm thick strip was 66 R_B. These hardness values are less than the hardness of standard Almen strips i.e. 44 to 50 RC. As far as shots are concerned they were cast steel shots of hardness 40 to 50 RC, other peening conditions were normal.

Mr Picard to M Cardon (Session Reporter)

M. CARDON, vous avez présenté différents paramètres de l'opération de grenaillage que l'on peut contrôler et reproduire pour réaliser les conditions optimales de grenaillage définies au préalable pour une pièce, mais il me semble que vous n'avez pas insisté suffisamment sur le contrôle des grenailles à la fois pendant le fonctionnement de la machine ou entre deux opérations.

Pouvez-vous s'il vous plait compléter brièvement sur ce point et nous dire en particulier si vous considérez qu'un contrôle toutes les 60 h comme cela a été rapporté ce matin par des auteurs de publication, vous parait suffisant?

M Cardon

Le contrôle des grenailles, pendant le fonctionnement de la machine est naturellement très important. Des précautions sont généralement prises au niveau d'une machine pour le tri à la fois dimensionnel et de forme des grenailles, et les machines modernes peuvent comporter des systèmes de tri dimensionnel et des systèmes de tri de forme. Malheureusement ces derniers systèmes ont des rendements assez faibles et il sera nécessaire soit de dériver seulement une partie du flux en circulation vers le système trieur de forme, soit de multiplier les trieurs. Pratiquement on constate que en dérivant une quantité de l'ordre de 5 à 10% du flus, les résultats sont généralement satisfaisants.

Il faut naturellement enlever tous les polluants de la grenaille en circulation en particulier les produits divers soit résultant de la projection, soit introduits accidentellement dans le circuit.

Enfin il faut admettre que le mélange de dimension et de forme de grenaille tel qu'il existe dans des grenailles neuves, dépend à la fois du mode de fabrication du fabricant, de la disposition des tamis qu'il utilise. Il n'en est pas forcément de même à partir du moment où l'on a introduit dans une machine une grenaille qui à l'origine correspondait à la même spécification que celle du fabricant mais qui par suite de l'usure qu'elle subit dans la machine va voir les proportions entre les différentes granulométries qui la composent évoluer. Bien sûr on peut introduire des tamis multi-étagés plus ou moins complets, mais il n'empêche que l'on aura tou jours dégradation des grenailles vers les dimensions les plus fines et que donc les proportions évolueront.

Il me semble donc qu'il reste absolument nécessaire d'effectuer des contrôles à périodicité relativement rapprochée sur les grenailles en circulation, mais il est nécessaire de faire des prélèvements représentatifs, c'est à dire à la sortie des organes de projection et également en quantité suffisante pour que l'on puisse utiliser des systèmes du type diviseur Tyler pour obtenir des échantillons représentatifs. Les tamis utilisés pour ces contrôles devront comporter, outre les tamis caractéristiques de la grenaille telle qu'elle est établie par les spécifications, soit à partir de nor mes, soit par l'utilisateur, des tamis complémentaires au-dessus et en dessous pour avoir une idée du comportement des grenailles pendant le travail. Il me semble qu'un tel contrôle devrait, en l'absence d'une expérience de longue durée sur le comportement des grenailles en service, avoir lieu une fois par poste de travail et une fois avec chaque changement de pièce ou chaque changement de maquette éprouvette ALMEN. Le résultat de ces expériences permettrait éventuellement d'allonger cette périodicité, toutefois, il est bien connu qu'il peut y avoir des problèmes de qualité de grenaille d'une livraison ou d'un fournisseur à l'autre, ou des problèmes de déréglage machine et que à défaut d'effecteur des examens insuffisamment rapprochés, on court de grands dangers d'obtenir des résultats peu cohérents.

4

The mechanics of shot peening
Le mécanisme du grenaillage de precontrainte
Vorgänge beim Kugelstrahlen

4a STRUCTURES

EFFECTS OF SHOT PEENING ON PROPERTIES OF CARBONITRIDED CASE WITH RETAINED AUSTENITE,
S PAKRASI & J BETZOLD

D Kirk

1. How, precisely, were the intensities of α and γ reflections measured?

2. Do the residual stress values in Fig. 3 refer to the austenite phase or the martensite phase? With 50% austenite the stress in this phase is as important (or more important) than that in the martensite phase.

S Pakrasi

1. The intensities of α and γ reflections were measured within an accuracy of ± 1%. All samples were measured several times under constant conditions of measurement (Mo $k\alpha$ – radiation).

2. The residual stress values refer to (211) reflection of the martensite phase. In spite of its high content in the initial stage, the austenite does not remain, both qualitatively and quantitatively, the same during the shot peening treatment. A considerable $\gamma \rightarrow \alpha$ phase transformation takes place and accordingly the content of austenite decreases rapidly. Due to its relatively weak intensities, measurements on samples with small contents of austenite are difficult and the results are less reliable. Besides that, the texture additionally aggravates the measurement on austenite phase. Therefore, instead of fading reflection of austenite only the reflection of martensite has been measured for the determination of residual stresses.

PLASTICALLY DEFORMED DEPTH IN SHOT PEENED MAGNESIUM ALLOYS,
W T EBIHARA, N F FIORE & M A ANGELINI

M O Speidel

This paper deals with shot peening of magnesium allogs. How did shot peening improve the fatigue resistance of the magnesium allogs and how did it influence corrosion fatigue and stress corrosion cracking of magnesium allogs? What is the effect of the observed twinning on these phenomena.

N F Fiore

Alloys AZ91, ZE41, and EZ33 peened to Almen intensity 5 experienced 25%, 25% and 35%, respectively, increase in rotating beam fatigue lives over unpeened specimens. No influence of peening intensity or peening material was noted on 5% salt fog exposure tests on these alloys. Corrosion fatigue and stress corrosion tests were not performed on the alloys. The effects of the twinned structure on the mentioned properties were not studied. This area, however, deserves consideration for further study.

4b RESIDUAL STRESS METHODS

METHODE DE LA FLECHE, METHODE DE LA SOURCE DES CONTRAINTES RESIDUELLES,

A NIKU-LARI & J F FLAVENOT

M Wilhelm

You have shown a slide not included in your printed version exhibiting the depth profiles of residual stresses in case hardened specimens. The shot peened specimen had not been tempered after case hardening. Have you also results with specimens empered before shot peening? What are the differences? Would you please further comment the curves?

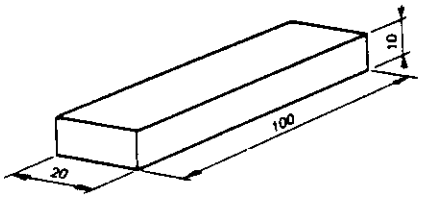
A Niku-Lari

Le cas des pièces cementées ayant subi un revenu duant grenaillage n'a pas fait l'objet d'une etude particuliere.

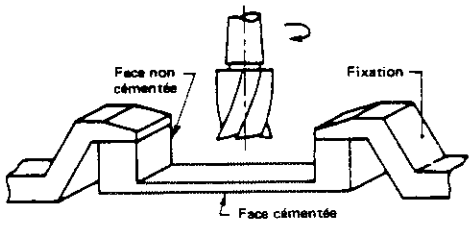
Les mesures ont été effectuées sur des éprouvettes en acier 16NC6 traitées dans les conditions indiquées dans le tableau ci-dessous. Le mode de préparation des éprouvettes de mesures à partir d'une éprouvette de traitement de 10 mm d'épaisseur est indiqué ci-dessous.

Sur les figures 1 et 2 on notera que les profils de dureté correspondent bien aux répartitions de contraintes résiduelles obtenues. C'est en effet l'éprouvette repérée (2),cémentée, grenaillée, qui présente la dureté et la contrainte résiduelle les plus élevées dans la couche superficielle. On remarquera également l'influence du revenu et du grenaillage sur l'allure des contraintes résiduelles. Le grenaillage permet d'augmenter considérablement la contrainte résiduelle superficielle.

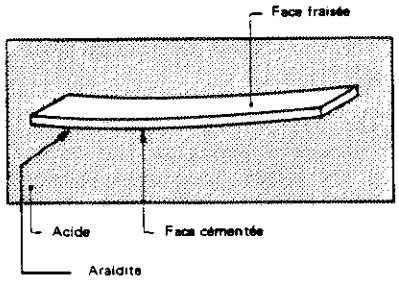
Repère de l'éprouvette	*Traitement de cémentation*	*Revenu*	*Grenaillage*	*Épaisseur de l'éprouvette avant usinage chimique* (mm)
(1)	Cémentation gazeuse de 2 heures à 900 °C suivie d'une trempe directe à 840 °C	—	—	2,22
(2)	Identique	—	Intensité Almen de 0,37 mm. Bille acier coulé ∅ 0,4 mm	2,13
(3)	Identique	à 180 °C pendant 1 h	—	1,82



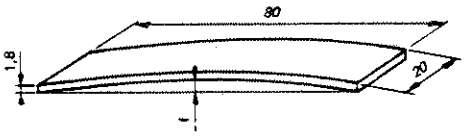
a) Éprouvette de traitement.



c) Dissolution chimique des couches perturbées par le fraisage.



b) Prélèvement de l'éprouvette de mesure par fraisage.



d) Éprouvette de mesure des contraintes.

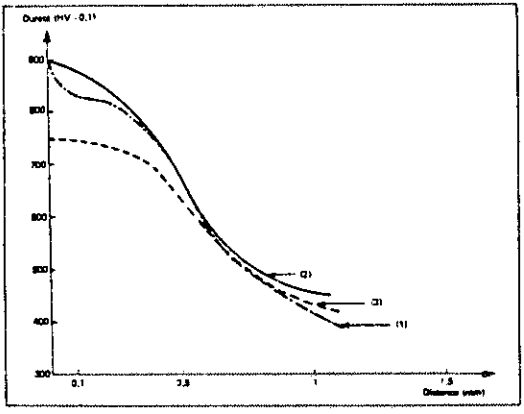


Fig. 1: Profils de dureté des éprouvettes.

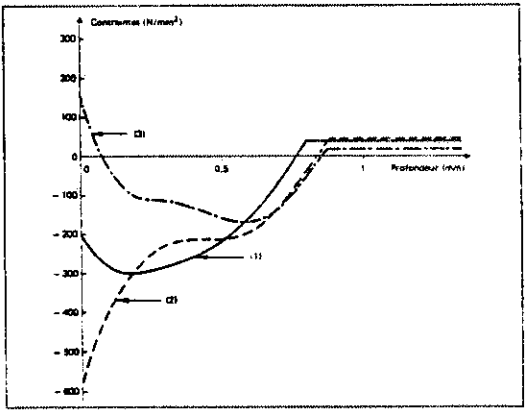


Fig. 2: Repartition des contraintes residuelles dans une pièce d'epaisseur 10 mm.

T Ericsson

Your depth profiles of residual stress always show an abrupt break just below the shot peened layer. The core stress is low and constant. The same was shown for a carburized layer. This seems "unphysical". Does it depend on approximation and assumptions in your calculations?

A Niku-Lari

We have measured residual stresses from the peened surface up to the plastically deformed layer. The distribution of the residual stresses in the rest of the part is just calculated by the equilibrium of the internal forces and bending moments according to the thickness of the specimen (see Fig. 3).

This is the reason why all profiles of residual stresses show an abrupt break just on the border between the shot-peened and unpeened layers.

This "unphysical" phenomena is not a natural effect but only a "computer matter" without any significance. The value of the core stress depends on the thickenss of the part. All residual stresses we have shown in the paper have been measured on a thin specimen, and then calculated for a 20 mm thick part. The core stresses become in this case very low (Fig. 3).

MEASUREMENT OF STRESSES INDUCED BY SHOT PEENING
S S BIRLEY

H E Franz

You have compared the residual stresses obtained by two totally different methods: X-Ray and hole drilling methods.

Have you taken in account that two different volumina of the material are concerned by the measurement?

S S Birley

The two techniques involve different volumes of metal. The X-Ray method for copper radiation in aluminium involves typically a depth of 25μM and (for the X-Ray film technique) 2mm diameter. The incremental hole technique involves drilling by small steps to a depth of approximately 1.5mm, a hole of 1.5mm diameter. Measurements are made on strain gauges which are remote (1.5mm) from the hole being drilled.

In the presentation, the surface stresses measured by X-Rays, were compared with those from incremental hole drilling. Because the latter technique is not accurate within the first 8% of depth from the surface, to obtain surface stresses it was necessary to extrapolate the data for depths greater than 8% back to the surface. Therefore two different things are being compared.

Further aspects are relevant here. We are often dealing with stress fields which vary non-uniformly both with depth and along the surface, (for example, near welds). In such situations, the specific surface stress value obtained by the X-Rays will depend on the type of tube employed. This is because the energy of the target material influences the penetration into the metal – which, of course, would give different stress values in a non-uniform stress field with depth.

Regarding the hole-drilling technique, there are two question to be considered. Firstly, the response of the three elements of the rosette will depend on their

position with respect to the non-uniform surface gradient. Work is underway at CEEB (UK) to investigate this effect and could result in modified equations for the analysis of the strain gauge data. Secondly, the calibration constants for the hole-drilling technique are those which are obtained from a uniform stress field, thus leading to inaccuracies. This is because there is no known non-uniform stress-field which can be applied so as to obtain the calibration constants. Finite element modelling by the authors will help resolve this problem.

The two techniques clearly involve completely different principles of measuring surface stresses, and therefore it could be argued that close agreement of stresses obtained by the two techniques is completely fortuitous. This could also be said of other techniques presented at the conference. I personally would like to see a wider discussion of stress measurement techniques and their significance and interpretation with respect to the numerous applications possible.

RESIDUAL STRESSES AND RETAINED AUSTENITE IN SHOT PEENED STEELS, D KIRK

T Ericsson

Were the tensile residual stresses at short lives measured after tensile or compressive peaks? This is known to affect the value of the observed residual stress.

D Kirk

The tensile residual stresses observed at short lives were measured on specimens that fractured during the tensile part of the last fatigue cycle.

T Ericsson

The as-carburised residual stress curve in Fig. 3 is very unusual. Can you give details about the background?

D Kirk

The as-carburised residual stress curve shown in Fig. 3 is, in fact, quite common for thick cases produced in alloy steel components. This particular steel is of the air-hardening variety. Transformation to martensite starts at the case/core interface and proceeds outwards and inwards. When a case is relatively thick a large amount of sub-surface transformation occurs before the extreme surface transforms. This pushes the surface into tension which is not completely offset by final surface transformation. For that reason shot peening is very useful.

General Comments

G Nachman

Dr Fuchs, in sponsorship with Metal Improvement Co., developed residual stress curves on 44-50 Rc spring steel, 53 Rc hard steel and aluminum 7075T6 using different intensities and shot sizes under the etching method of layer removal on these strips in the early 1960s.

M Ladoux

Je voudrais seulement signaler que des essais sur 2024-2618 7075 T6 nous ont montré une très bonne relation entre la flèche obtenue sur éprouvettes ALMEN N et les

contraintes de compression obtenues sur les éprouvettes en alliages d'aluminium cités ci-dessus; ceci avec differents types de billes et différentes intensités de grenaillage.

Ces experimentations ont permis des applications industrielles avec de bons resultats.

U Wolfstieg

Die Verbreiterung von Röntgeninterferenzlinien Kann Bekanntlich auf Verbreiterungen durch die Apparatur, Verbreiterungen aufgrund von Teilchengrössen in der Probe und Verbreiterungen durch Mikrodehnugen (oder-Spanungen) zurückgeführt werden. Im vorliegenden Fall interessieren nur die Mikrodehnungen. Es ist daher besser die Mikrodehnungen zu berechnen anstelle der Halbertsbreiten anzugeben. Nur dann werden die Ergebnisse quantiativ vergleichbar mit schon vorliegenden oder zukünftigen Ergebnissen anderer Autoren.

4c SURFACE CONDITIONS

THE IMPROVEMENT OF FATIGUE AND SURFACE CHARACTERISTICS ALLOY 7075-T6 BY SECONDARY PEENING WITH GLASS BEADS,

A SNOWMAN & R G SCHMIDT

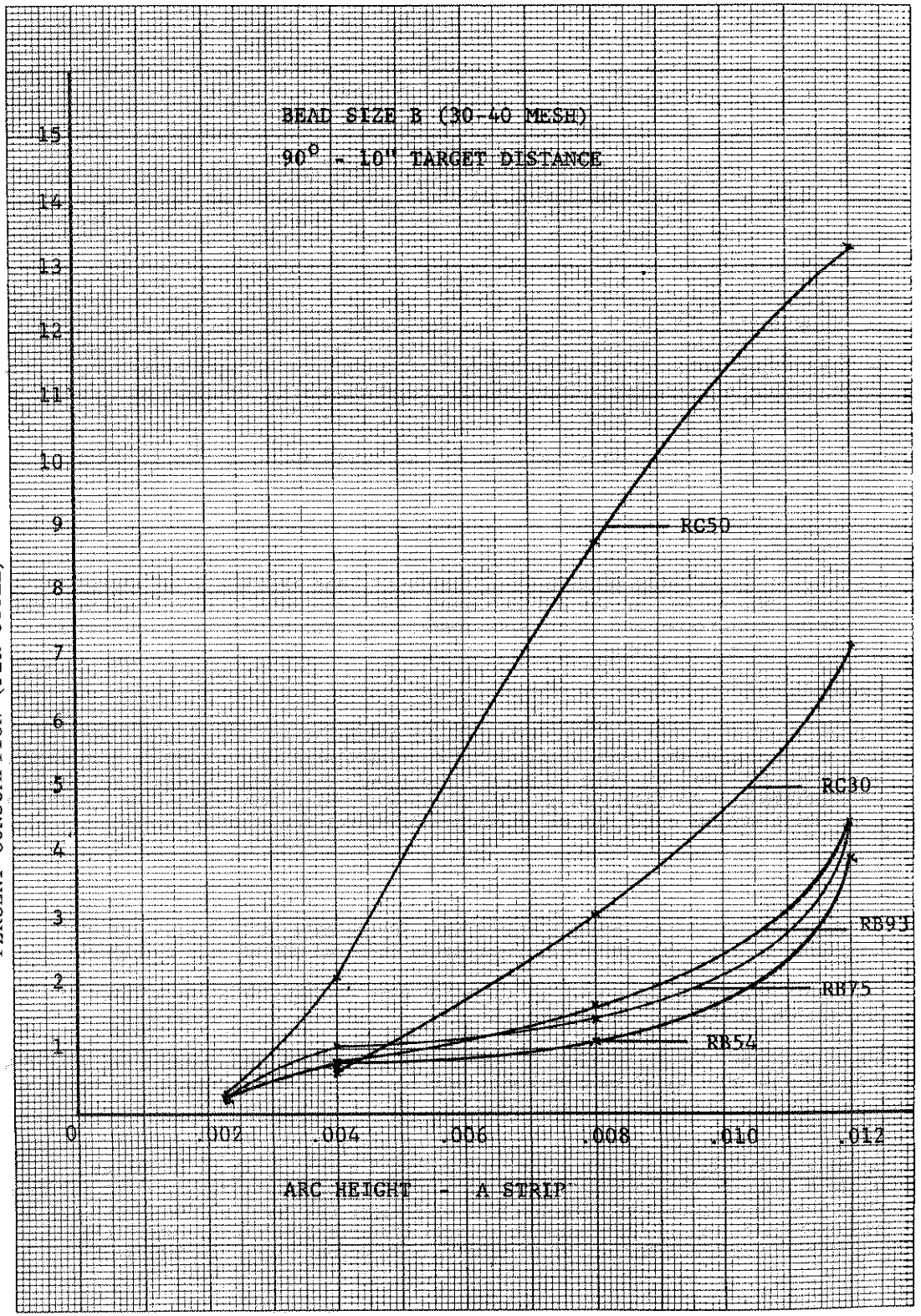
M Picard

You studied the influence of shot peening upon fatigue characteristics of some materials.

Did you take a note of the rate of broken glass beads during the process or did you only examine the surface of the materials after shot peening?

R G Schmidt

Our objective in the paper was not directed toward evaluating the breakdown of the beads, but rather the influence of secondary peening toward extending the fatigue life and the improvement of the final surface smoothness. However, we have completed breakdown studies and published data comparing the bead consumption rates with bead sizes and target hardness. (see the curves of the consumption rate for Potters size B glass spheres). At Potters, "consumption rate" is defined as the percent increase in weight of glass beads passing an arbitrarily selected screen after 4 cycles of blasting. The consumption rate is the average percentage of charge weight consumed per cycle. One blast cycle is the time required for a pre-weighed glass bead charge to flow through the nozzle one time. The selection of screen size determining consumed material is dependent upon the size distribution range of beads tested. For example, size H (100-140 mesh), the material passing through the 140 mesh screen is arbitrarily classified consumed material. Size AE (100-170 mesh) which was the media used in our paper, consumes at approximately the same rate as size H when tested under the same parameters.


BEAD SIZE B (30-40 MESH)
90° - 10" TARGET DISTANCE
PERCENT CONSUMPTION (PER CYCLE)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
RC50
RC30
RB93
RB75
RB54
.002
.004
.006
.008
.010
.012
ARC HEIGHT - A STRIP

INFLUENCE DE L'ETAT DE SURFACE SUR LA RESISTANCE
A LA FATIGUE D'UN ACIER A 13%. DE CHROME
POUR AILETAGES DE TURBINES A VAPEUR
J R DONATI, J GRATTIER, S H MASSON & F TERNON

M Jouvie

"M Grattier a dit que les contraintes résiduelles de compression se sont relaxées sous l'action de fortes contraintes alternées. Peut-il préciser les valeurs de relaxation des contraintes résiduelles et celles correspondantes, des contraintes alternées?"

J Grattier

En sollicitation alternée, la relaxation des contraintes résiduelles superficielles est une fonction croissante de la valeur initiale de cette contrainte résiduelle et de l'amplitude de la sollicitation de fatigue subie. Les valeurs numériques correspondant aux différents états de surface étudiés sont précisées dans le tableau III.

Les contraintes résiduelles superficielles subsistant après cyclage de fatigue sont plus élevées pour l'état de surface grenaillé (n°7) que pour l'état meulé (n°3).

U Wolfstieg

Sie haben Untersuchungen angestellt bei erhöhter Temperatur und unter Korrosionsangriff. Wie beurteilen Sie das Verhalten, wenn beim Betriebseinsatz mechanische Spanunngen hinzutreten und an den höchstbelasteten Stellen der Turbinenschaufeln vielleicht Kriechen einsetzt?

J Grattier

L'acier à 13% de chrome que nous avons étudié à température ambiante est utilisé pour les ailetages des corps basse pression de turbine à vapeur dont la température de service est comprise entre 20 et 80°C; dans ces conditions, la seule relaxation des contraintes superficielles de compression à craindre proviendrait de contraintes cycliques alternées alors que les ailetages subissent des efforts répétés en traction.

M O Speidel

(M Grattier) One has not found a significant improvement in corrosion-fatigue resistance of 13% chromium steels in chloride solution due to shot peening.

Could this be due to the growth of corrosion pits through the surface layer of compressive stresses?

Why do you think the improvement of fatigue in air due to shot peening was only very moderate with your steam turbine blade steel?

J Grattier

La résistance à la fatigue en milieu chloruré des aciers à 13% de chrome est reliée à leur résistance à la formation de piqûres superficielles. Il est possible, comme vous le supposez, et bien que nous ne l'ayons pas vérifié directement sur le produit étudié, que la croissance de piqûres traversant la couche superficielle en compression, annule à terme l'effet bénéfique du grenaillage. Toutefois la

construction de la figure 5 montre que, pour un matériau de faible résistance intrinsèque, quelque soit le mécanisme mis en jeu, l'effet bénéfique que l'on peut attendre du grenaillage est très faible.

En ce qui concerne la résistance à la fatigue dans l'air, l'amélioration apportée par le grenaillage est réduite mais il faut noter que:

- l'état de surface de référence meulé présentait déjà des contraintes résiduelles de compression de -300 MPa.
- les sollicitations de fatigue étudiées conduisent à une relaxation partielle des contraintes résiduelles.

Toutefois l'effet maximal à attendre du grenaillage de précontrainte sur la limite d'endurance en sollicitations répétées dans l'air a pu être évalué à environ + 200 MPa sur l'amplitude de contrainte pour une contrainte moyenne de l'ordre de + 150 MPa.

5

Fatigue, steels
Fatigue, aciers
Dauerschwingverhalten, Stähle

THE STRENGTH OF SHOT PEENED PARTS? DESIGN CALCULATIONS AND SPECIFICATIONS,
H O FUCHS

C Verpoort

The Almen-intensity is not a reliable measure in all cases. One has to keep in mind that the shot peening process is a fatigue process to the surface layer. This will be explained in more detail in the papers of Wagner and Luetjering and Wang et al. at this conference. It was found that the shot peening velocity can be described as the stress amplitude and the shot peening time as the number of cycles in a fatigue test. But the same Almen-intensity value can be obtained by using different velocities and different time of shot peening. However, the factors "cyclic stress amplitude" and "number of cycles" cannot be exchanged in a fatigue test.

As a result of cyclic deformation during shot peening, the surface layer can show a "cyclic hardening" or "cyclic softening" like in a fatigue test. This "hardening or "softening-effect" is not only influenced by the initial microstructure of the material, but also by the value of the applied stress amplitude respectively shot velocity.

The so called over-peening effect can be explained in the same way. Some materials show an increasing fatigue life with increasing time of shot peening (stainless steels, nickel-alloys), while for some other materials (low C-steels, titanium alloys) a decreasing fatigue life is found due to the cyclic softening of the surface layer. Sometimes there are additional reasons for this decrease, for example production of microcracks at martensite plates or grain boundaries during shot peening.

Another minor mistake of the Almen-intensity measurement occurs when the hardness of the Almen strip is different from the hardness of the work piece. Softer materials than the test strip will reach the saturation and complete coverage earlier and reverse for harder materials. (see paper of Clarke and Birley at this conference).

H O Fuchs

The remark of Dr Verpoort may have suffered in translation. If he means that the

Almen intensity alone is not sufficient to measure the effects of shot peening in all cases, I agree with him and have said so in the paper. I want to point out that it is sufficient in most cases, in particular in the applications to carbon steel quenced to develop martensite and then tempered. These are the most important applications of shot peening for the improvement of fatigue resistance, in terms of tonnage of parts treated and in terms of total cost of all the treated parts.

If "not a valuable measure in all cases" means that in some cases the Almen intensity is without value, then I must disagree. Almen intensity together with specification of the shot (by size and hardness) and degree of saturation (98%) minimum but perhaps far more tells us as much or more than a list of variables such as air pressure, exposure time, etc. The Almen intensity integrates these variables and knowledge about the shot permits us to pin down the elements of the integral.

The different surface structure and the hardening or softening produced by the repeated ball impacts are interesting, but they are minor effects compared to the self stresses (residual stresses) in applications to parts with notches or with crack prone surfaces; such parts represent the great majority of applications of shot peening for fatigue resistance.

Comparisons with polished specimens in push-pull tests can give us some insights into the changes produced by peening, but cannot be applied to predict the fatigue strength of peened machine parts unless the effects of stres gradients are carefully considered.

The data presented by Wagner and Luetjering confirm these opinions, in particular the differences they show between push-pull tests and rotating beam tests.

When peening is used to prevent stress corrosion the surface structure may be more im portant than in fatigue applications.

A Niku-Lari

How is the critical alternating tensile stress S_{cat} defined and where does one find suitable values for it?

H O Fuchs

S_{cat} is defined on a Haigh diagram for sharply notched parts by the horizontal line which fits the fatigue strengths with large mean tensile stress and by the line inclined at 45 degrees which fits the fatigue strengths with large compressive mean stress, both within the elastic region. The horizontal line satisfies the equasion $S_{cat} = S_a$. The inclined line satisfies $S_{cat} = 0.5(S_a + S_m)$ where S_m is negative or zero. When no Haigh diagram of fatigue strengths is available one finds $S_{cat} = 0.5$ S_a for very sharply notched parts in rotating bending; the value from a single test condition is, of course, less reliable than the value found by fitting a line to points which represent many test conditions.

S_{cat} is given as 70 MPa for hard steel, 30 MPa for mild steel, and 20 MPa for high strength aluminum by Fuchs and Stephens (1980). These are mean values and therefore too high for design calculations. As they are all very low the designer will assume $S_{cat} = 0$, corresponding to Almen's dictum "Fatigue failures are tensile failures" and to the observation that in fatigue failures of parts the cracks propagate in the tensile opening mode, the mode I of fracture mechanics.

T Ericsson

When you draw the "HAIGH" diagram for shot peened materials, should the yield limit curve use the "virgin" material yield strength or the workhardened?

H Fuchs

The Haigh diagrams shown in the paper indicate only gross yielding which extends beyond the "peened depth," (i.e. the depth to which peening produced plastic deformation). For this reason one should use the yield strength of the un-peened material. Local yielding in the roots of notches will occur at much smaller values of nominal stress.

We know that shot peening remains effective in increasing the fatigue limit at stresses far beyond those which produce yielding in the roots of sharp notches. Therefore we use the nominal stresses in predicting crack arrest.

In a detailed analysis of the stress fields at the tips of small fatigue cracks originating from notches in shot peened parts, one would use the local yield stresses which may or may not be substantially different from the bulk yield stress of the un-peened material. The author doubts that such an analysis has yet been made.

The changes in yield strength are important in those less frequent applications of shot peening when it is used to improve the wear resistance of materials whose hardness and yield strength are increased by peening.

U Wolfstieg

Darf ich zu Ihrer Bemerkung, dass die Analyse von Spannungs-und Eigenspannungsverteilungen an scharfen Kerben nur mit der Finiten Elemente Methode möglich ist, ergänzen: Am inst. in Karlsruhe wourde ein gerärt eingerichtet, das röntgenographische Eigenspannungsbestimmungen mit Messflächen bis herab zu 0,1 mm Durchmesser ermöglichte. Es können damit und in entsprechend scharfen kerben Messungen durchgeführt werden.

H Fuchs

I am glad to learn that self stresses can now be measured by X-ray diffraction in areas as small as 0.1mm (0.004in). Details of the apparatus and measured data on the distribution of self stresses in notches will be most welcome.

SHOT PEENING AND FATIGUE OF MATERIALS,
H WOHLFAHRT

A Niku-Lari

Meinen Sie nicht, dass die höheren Eigenspannungen bei gekerbten Proben dadurch zustande gekommen sind, dass die gekerbten proben vor dem Kugelstrahlen gehärtet waren.

H Wohlfahrt

Wie in den Bildern 3a und 3b zu sehen, lassen sich tatsächlich bei gehärteten Proben, die kugelgestrahlt werden, betragsmäßig größere Druckeigenspannungen erzielen als bei verguteten oder gar bei normalisierten Proben. In Bild 14a wird jedoch ein Eigenspannungsverlauf unterhalb der Kerbgrundoberfläche mit den Eigenspannungsverläufen unterhalb glatter Flächen bei einsatzgehärteten Proben völlig übereinstimmender Härte verglichen. Der beträchtlich größere Druckeigenspannungsmaximalbetrag unterhalb der Kerbgrundoberfläche kann deshalb nur der fließbehindernden Wirkung der Kerbe selbst zugeschrieben werden.

C Sayettat

Avez-vous étudié l'effet du grenaillage sur éprouvettes entaillées traitées dans la masse. En particulier la stabilité des contraintes résiduelles lors des sollicitations dans ce cas.

H Wohlfahrt

Es wurden durchgehened wärmebehandelte gekerbte Proben kugelgestrahlt. Sie zeigten in der Oberflächenschicht vergleichbar grosse Druckeigenspannungen wie die einsatzgehärteten und kugelgestrahlten Proben.

Es werden Versuche zum Verhalten der in Kerben vorliegenden Eigenspannungen bei Dauerschwingbeanspruchung durchgeführt. Im Augenblick kann ich Ihnen aber noch keine Ergebnisse nennen.

M Jouvie

M WOHLFAHRT a indiqué qu'un grenaillage de précontrainte d'éprouvettes entaillées (entaille en forme de v, semble-t-il) avait provoqué des contraintes de compression autour de l'entaille. M WOHLFAHRT pense-t-il qu'on obtiendrait des résultats semblables avec une entaille plus fermée?

M Wohlfahrt

Im Rahmen der vorgetragenen Untersuchungen wurden keine Eigenspannungsmessungen an Kerben unterschiedlicher Form ausgeführt. Man kann jedoch davon ausgehen, daß auch bei Kerben einer anderen, z.B. stärker geschlossenen Form, ähnliche Ergebnisse wie bei der angewandten Kerbform zu erzielen sind, das heißt gegenüber dem Ergebnis unter glatten Flächen erhöhte Druckeigenspannungsmaximalbetrage unterhalb Kerbgrundoberflächen, Dabei muß natürlich vorausgesetzt werden, daß die Kerbe überhaupt noch hinreichend neit und der Kerbgrundradius noch hinreichend groß für eine Kugelstrahlbehandlung ist.

Siehe auch Kommentar von Prof. Fuchs zu diesem Punkt.

H Fuchs (Referring to the question of Mr Jouvie)

Comment on the higher self stresses at the bottom of notches:

TODD has shown such self stress concentrations by finite element analysis. Published in "Experimental Mechanics", Title: "Self stress concentration", year approximately 1973.

J L Lebrun

Dans votre graphique de la figure 8 vous montrez les améliorations respectives de la tenue à la fatigue alternée dues aux contraintes résiduelles et au durcissement apportées par le grenaillage. Comment tracer le cas où le grenaillage apporte un adoucissement superficiel du matériau (cas des materiaux très durs figure 4).

H Wohlfahrt

Das ist eine sehr interessante Frage. Bei sehr harten Werkstoffzuständen ($\gtrsim$ 700 HV), wo die Rißausbreitung unter der Oberfläche beginnt, haben – wie im Manuskript angegeben – geringe Entfestigungen in oberflächennahen Schichten keine oder nur untergeordnete Bedeutung für die durch Kugelstrahlen erzielbaren Wechselfestigkeitsgewinne. Man muß jedoch annehmen, daß in etwas weniger harten Werkstoffzuständen

(≳ 500 HV) kugelstrahlbedingte Entfestigungsvorgänge die erreichbare wechselfestigkeit beeinträchtigen können, wenn die zum Versagen führenden Risse von der Oberfläche ausgehen, was aufgrund der Ergebnisse von (21) in solchen Werkstoffzuständen zu vermuten ist. Untersuchungen, die sich unmittelbar mit diesem Punkt befassen sind mir nicht bekannt. Es ist aber in diesem Zusammenhang bemerkenswert, daß von (2) im Bereich mittlerer Festigkeiten ($\sigma_{-D,2} \approx$ 1100 N/mm^2) ein Minimum der kugelstrahlbedingten Wechselfestigkeitszunahmen beobachtet wurde.

U Wolfstieg

Die Verwendung des Begriffs Spannungsabbau ist nicht immer ganz korrekt. In Kugelgestrahlten Teilen reagieren die verfestigten Randschichten bei plastischer Verformung anders als das Kernmaterial. Es kommt zu Änderungen der Eigenspannungsverteilungen.

H Wohlfahrt

Es ist richtig, daß bei der Schwingbeanspruchung eigenspannungsbehafteter Teile nicht nur eine Verringerung der Beträge von Eigenspannungen ("Eigenspannungsabbau") eintreten kann, sondern je nach Werkstoffzustand, Betrag der Ausgangseigenspannungen, Beanspruchungsart und Beanspruchungsamplitude auch Eigenspannungsänderungen der Art auftreten können, daß z.B. die Oberflächeneigenspannungen betragsmäßig zunehmen oder gar das Vorzeichen ändern. So wurde bei der Zug-Druck-Beanspruchung von Stählen in Zuständen geringer Festigkeit und mit relativ geringen Ausgangseigenspannungen eine Zunahme der Oberflächeneigenspannungsbeträge innerhalb der ersten Lastwechsel beobachtet und auf Plastizierungen infolge einer gegenüber dem Matrixwerkstoff erniedrigten Oberflächenstreckgrenze zurückgeführt (44). Bei werkstoffzuständen mit betragsmäßig großen Eigenspannungen, wie sie beim Kugelstrahlen erzeugt werden, kommen aber nach bisherigen Erfahrungen außer in extremen Sonderfällen (Schwellbeanbeanspruchung mit Maximalspannungen in der Größe der Streckgrenze) derartige Effekte nicht oder zumindest nicht sehr ausgeprägt vor. Es ist deshalb für solche, praktisch wichtige Zustände in erster Linie von Interesse, ob ein "Eigenspannungsabbau" auftritt oder nicht und welche Bedeutung er für das Dauerschwingverhalten hat. Zusätzlich kann wichtig sein, inwieweit der Eigenspannungsabbau gleichmäßig oder ungleichmäßig über dem Probenquerschnitt erfolgt (siehe Bericht von P. Starker, H. Wohlfahrt und E. Macherauch).

T Ericsson

You showed that the compressive residual stress in a notch is higher than on a smooth surface. Is this because some of the compressive residual stress on the smooth surface adjacent to the notch is transmitted into the notch and superimposed on the "proper" compressive residual stress in the notch? A consequence would then be that even if the notch itself is not peened, one will anyhow observe a compressive stress in the notch bottom.

H Wohlfahrt

In the described experiments the notches themselves as well as the surrounding material were shot peened. We have no direct evidence about residual stress distributions in notches which are not peened whilst the surrounding material is peened. Other investigations (32) have shown that unpeened areas around individual shot indentations exhibit compressive residual stresses. However, in the case presented here I am sure that the notch effect itself – that is to say a multi axial state of stess and hence a hindering of plastic flow – is the reason for the

(44) S. Ziegeldorf und H. Christian (1978). Härterei-Teohn. Mitt., 33, 315-317.

extraordinary high magnitude of compressive residual stresses below the notch surface.

R Martin

Has any work been done on the effects of shot-peening on fretting damage?

H Wohlfahrt

I am rather sure that investigations have been made on the effects of shot-peening on fretting damage. But at the moment I cannot tell you any results.

5a SPRINGSTEELS

INFLUENCE DU GRENAILLAGE DE PRECONTRAINTE ET DE LA RUGOSITE AVANT GRENAILLAGE SUR LA TENUE EN SERVICE D'ACIERS A RESSORTS

C GRANOTTIER

C Verpoort

I would like to make a short comment on surface roughness after shot peening and the loss of weight during peening.

Prof. Edington (University of Delaware, Newark, USA) who is working in erosion by hard particles found a very high surface strain of $\varepsilon = -5$ in the case of a copper single crystal after erosion. The loss of weight during erosion or shot peening is due to this high strain, crack initiation at these overlaps and final fracture. In Fig. 1 you see these overlaps and flakes. In the tapersections of these overlaps we find deep notches. These notches are not detected during mechanical measurement of the surface roughness but they lead to an early crack initiation in the shot peened surface especially after overpeening.

As mentioned already the loss of weight is a function of microstructural parameters like work-hardening, yield stress, initiation and propagation of cracks and the fracture toughness. To show this effect we investigated two different heat treatments, an aged condition (Condition B) and an over-aged condition (Condition F). The material used was a precipitation hardenable austenitic steel, A 286. In Fig. 2 the loss of weight is plotted as a function of the shot peening time. The pressure of 5 (10) bar corresponds to a ball velocity of 20 (30) m/s. The overaged condition with a lower ductility and lower mechanical properties shows a higher rate of erosion than the aged condition.

Fig. 1: Surface roughness after shot peening, SEM and light-microscopy.

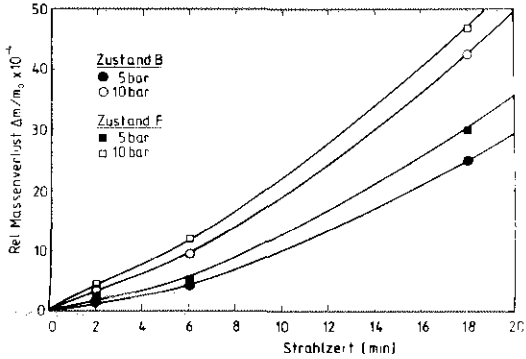


Fig. 2: Loss of weight as a function of the shot peening time for aged (condition B) and over-aged (condition F) conditions for two different velocities.

DER EINFLUSS DES KUGELSTRAHLENS AUF DIE DAUERFESTIGKEIT VON BLATT UND PARABELFEDERN,
G KÜHNELT

Mr Kiefer

Wie ist bei den Untersuchungen "Einfluss bei Erhöhter Temp." die Zeit berücksichtigt? Gibt es Langzeit-Versuche zur Übertragbarkeit auf die Praxis?

G Kühnelt

Die Proben werden Ca. 1/2 H vor dem Test erwärmt und dann in KUrzer Zeit zum Bruch gefahren.

U Wolfstieg (General Remark)

(nach einer längeren Diskussion als letzter Diskussionsbeitrag:)

Grundsätzlich führt die Plastifizierung einer Probe mit verfestigtem Rand wenn gereckt wird (positive plast. Dehnungen) zu Zugeigenspannungen im Rand, wenn gestaucht wird (negative plast. Dehnungen) zu Druckeigenspannungen im Rand der Probe. Bei Versuchen mit einem Federstahl ähnlich dem in Beitrag 5 genannten stahl zeigten Kugelgestrahlte und 1% gereckte Proben eine Erniedrigung der Dauerwechselfestigkeit gegenüber der ganz unbehandelten Probe, Kugelgestrahlte und 1% gestauchte Proben eine Erhöhung der Dauerwechselfestigkeit, die jedoch deutlich unter der ker kugelgestrahlter Probe blieb.

ROLE DU GRENAILLAGE SUR LA DUREE DE VIE EN TORSION ONDULEE D'UN ACIER A RESSORT TRAITE A HAUT NIVEAU DE RESISTANCE

J HEINRICH, C MAS, R LEMAITRE, J P LUMET & M BOUSSEAU

R HENRI

1) Influence de la température après le shot peening

2) Qualité du shot peening sur pièce chauffée à 100 - 200 - 300 - 400°C. Influence sur la tenue aux flexions alternées et sur le fluage des ressorts fabriqués à chaud à partir d'aciers Cr SC7, 45 SCD6 de Ø fil 10 à 20 mm

J HEINRICH

En ce qui concerne nos résultats, un revenu apres le grenaillage diminue sensiblement les contraintes résiduelles et la durée de vie de nos éprouvettes. Nous n'avons pas éffectué de grenaillage sur des éprouvettes chauffées

5b AUSTENITIC AND OTHER STEELS

INFLUENCE OF SHOT PEENING ON THE FATIGUE BEHAVIOUR OF A PRECIPITATION HARDENABLE AUSTENITIC STEEL,
E HORNBOGEN, M THUMANN & C VERPOORT

H O Fuchs

I would like to ask the authors to give some more information about the microstructure at high temperature.

C Verpoort

For a high-temperature-component like a turbine blade it is very important to have a good creep resistance. Therefore a large grain size is used. (++ in table 1). In addition, the crack propagation of materials with a large grain size is very slow (++ in the table) because of the reversibility of slip at the crack tip. This is one possible explanation as shown in the model of Hornbogen and Zum Gahr. (1,2). If the γ'-particles are sheared (Fig. 1) we find a crack propagation of $n \cdot b$. During crack propagation some dislocations can slide back one the same slip plane so that the final propagation is only $(n - n_R) \cdot b$.

On the other hand the crack initiation behavior of a material with a large grain size is bad (- in the table) because many dislocations pile-up in a slip band leading to an early crack initiation at high slip steps in the surface. (Fig. 2). The best possibility to retard an early crack initiation is to disperse the planar dislocation movement. A very effective way is to create a microstructure which shows a dispersion of incoherent particles and a dense network of sub-grainboundaries (++ in the table) introduced by shot peening. Therefore we find a good crack initiation in the surface (small grains or subgrains), a good creep resistance in the interior (large grains) and a good resistance against crack propagation in the interior (large grains).

The combination of all these positive effects leads to an optimum fatigue life at high temperature. W. Renzhi *et al* presented a paper at this conference about shot peening and high temperature fatigue. They found the same results for different superalloys.

References

1) E. Hornbogen, K.H. Zum Gahr, (1976). Acta Met. 24, 581.

2) S. Floreen, R.H. Kane, (1980). Proceedings of the Fourth International Symposium Superalloys, ASM, Metals Park, Ohio, 595.

Table 1: The effect of microstructural parameters on High-Temperature-Fatigue:

	Crack Initiation	Crack Propagation	Creep
large grain size	-	++	++
small grain or subgrain size	++	-	-

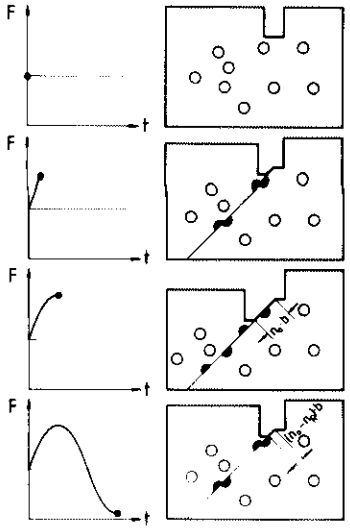


Fig. 1: Model of Hornbogen and Zum Gahr about reversibility of slip at a crack tip, (ref. 1).

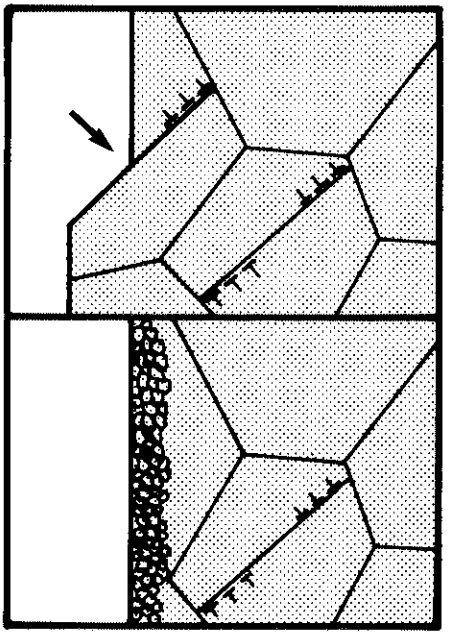


Fig. 2: Surface deformation of a material with a large or a small grain size.

7

Stress corrosion
Corrosion sous tension
Spannungsrisskorrosion

SHOT PEENING AND STRESS CORROSION, M O SPEIDEL

G P Balcar

With respect to the possible reasons for the effectiveness of glass bead secondary peening we have observed what we think is higher hardness of the compressed layer after the second peening with glass or possibly a peak hardness closer to the surface. We have this under study.

W. Köhler

In your last slide you recommended a.o. after shot peening with steel shot to peen with glass beads to eliminate the impurities from the surface of aluminium-alloys and to prevent herewith pitting corrosion. I may warn however of this procedure. We made such a treatment at a AlZnMg-alloy with the result that the danger of pitting corrosion was increased, as the iron-impurities were not eliminated but stronger pressed in the aluminium surface by the peening with glass beads. Only by additional wet peening by the so called TMSH-method can the impurities be eliminated from the aluminium surface.

M O Speidel

Thank you for your remarks.

General remarks

R Livesey

I am concerned at the number of fatigue tests presented which give poor results for peening where the test is an axial type, particularly at high stress levels and primarily of the push-pull type, where very rapid stress loss can occur and the result ends up only comparing the relatively rough peened surface with a smooth laboratory specimen and beneficial effects of the residual compressive stresses are lost.

N E Robinson

Shot peening together with a surface protection system against corrosion go a long way towards preventing stress corrosion cracking. I would like to know what is the max: exposure time to the atmosphere after shot peening?

M O Speidel

I am sorry I do not have the answer to that question.

UNTERSUCHUNGEN ZUR VERBESSERUNG DER SPANNUNGSRISSKORROSIONS-BESTANDIGKEIT EINER GESCHWEISSTEN HOCHFESTEN AL-LEGIERUNG DURCH KUGELSTRAHLEN

W KOHLER

W Schütz

It is very helpful that the author at least mentioned scatter in fatigue life, because it is a very important parameter. However, in Fig. 5, the impression is given that scatter decreases within numbers of cycles to failure for shot peened specimens and increases for the unpeened specimens. The former is contrary to all the available evidence (scatter always increases with numbers of cycles to failures).

W Köhler

Für die Berechnung der Zeitschwingfestigkeits-Geraden wurden für das ungestrahlte und kugelgestrahlte Material jeweils 20 Proben gefahren und ausgewertet. Wir sind uns bewußt, daß für eine verlaßlichere Auswertung auch im Hinblick auf die Streubreite eine noch größere Anzahl von Proben notwendig gewesen wäre.

Die Abnahme der Streubreite mit der Zyklenzahl bei dem kugelgestrahlter Material wurde durch zwei Proben, die bei geringer Zyklenzahl zu Bruch gingen, verursacht. Dieser Effekt wäre bei einer besseren Statistik wohl nicht aufgetreten.

A Snowman

Was there any relationship between the size of the bead used, the coverage and the surface finish (RMS value) of the samples? We have found that larger diameter beads normally give a rougher surface finish and that multi coverage with smaller diameter beads gives a smoother surface?

Was the surface finish or smoothness of samples 6 and 7 considerably better than that of samples 1 to 5?

W Köhler

The samples with single coverage had a smoother surface finish than the samples with multi coverage. But there was no relationship between surface finish and the much improved S.C. results with samples 6 and 7.

R Clausen

Bitte geben Sie die "optimierten Bedingungen" an, die zur wesentlichen Steigerung der Spannungsrisskorrosionsbeständigkeit geführt haben (siehe Abb. 3, no. 6 und 7).

W Köhler

In der Regel beginnt die Rißbildung in der Bindezone an der Wurzel der Schweißnaht. Wir haben daher an der Wurzel der Naht eine zusätzliche Behandlung außer der im Paper angegegenen Strahlbehandlung angewendet. Da die Untersuchungen noch nicht abgeschlossen sind, kann ich hierzu nichts Näheres angeben.

SOME COMMENTS ON SHOT PEENING AND HYDROGEN EMBRITTLEMENT OF NICKEL

D J DUQUETTE, N S STOLOFF & C VERPOORT

INTRODUCTION

It is well known that shot peening has a beneficial effect on stress corrosion cracking, fretting fatigue and delayed failure (McNitt, 1972). Some additional comments on the effect of shot peening on hydrogen embrittlement should be made.

Many materials like stainless steel, zirconium, 7075 aluminium and various steels show a reduction in ductility in the presence of hydrogen, often accompanied by a change in the fracture mode. The initiation site for cracks is dependent on the weakest interface in the presence of hydrogen. (Ashok et al, 1981).

EXPERIMENTAL PROCEDURE

Fatigue tests were performed on pure nickel (99.99% Ni) with an average grain size of 270 µm. The cylindrical specimens were shot peened with steel shot S 230 (SAE standard J 444) and an Almen-intensity A2=0.25 mm. The tests were carried out in a vacuum chamber at a frequency of 20 Hz and a stress ratio of R = -1. Ultra high purity hydrogen and argon (99.999% purity) purified by an additional gas purifier and a liquid nitrogen cold trap were used for the tests. The gas flow rate was kept constant (0.25 l/min.) at a pressure of 2 atm.

RESULTS AND DISCUSSION

The investigated material shows fatigue crack initiation at grain boundaries in hydrogen atmosphere while in an inert environment (argon or vacuum) transcrystalline crack initiation is found. (Fig. 1) The fatigue life in hydrogen gas is about 5-10 times shorter than in argon. (Fig. 2) The cracks propagate along grain

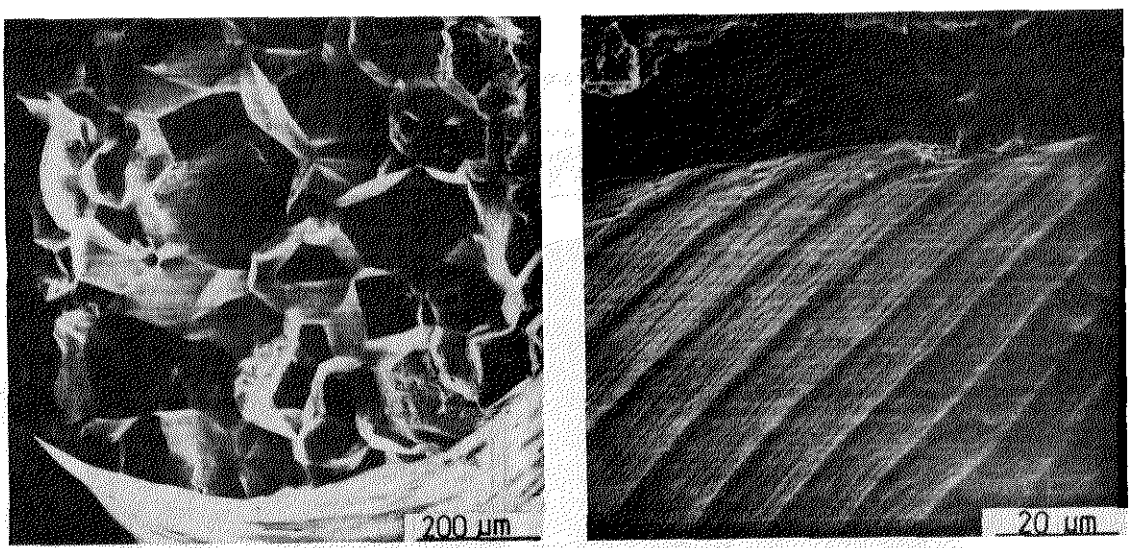


Fig. 1: Fatigue fracture surface of 99.99% Ni tested in hydrogen.

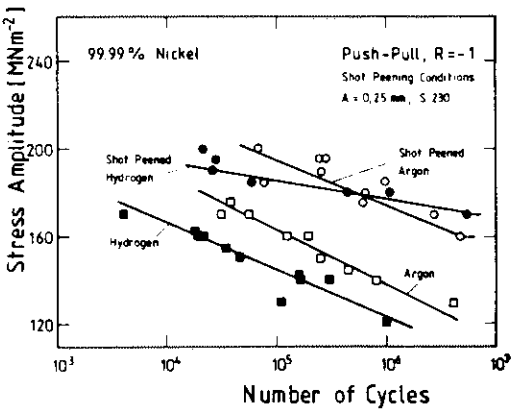


Fig. 2: S-N-curve for untreated and shot peened specimens.

boundaries. At high magnification striations can be seen on these grain surfaces. The spacing between these striations and steps is related to the time for the diffusion of hydrogen from the old crack tip to the new one. The rate of crack growth is determined by the transport of hydrogen to the crack tip, surface reaction with the new crack surfaces and diffusion of hydrogen to the embrittled zone ahead of the running crack. (Wei, 1981)

After shot peening the fatigue life in hydrogen as well as in argon is increased significantly. Surprisingly, even after the shot peening treatment crack initiation at grain boundaries is found in hydrogen-tests. It seems to be that slowed diffusion of hydrogen in the propagating crack is related to crack closure effects. In argon the cracks are initiated at slip bands. In the region of tensile residual stresses a zone of grain boundary cracks is observed. (Fig. 3)

CONCLUSIONS

Shot peening significantly improves the HCF-life of 99.99% Ni in both argon and hydrogen atmosphere. In this case, the micro crack growth rate is retarded by the compressive residual stresses in the surface layer.

ACKNOWLEDGEMENTS

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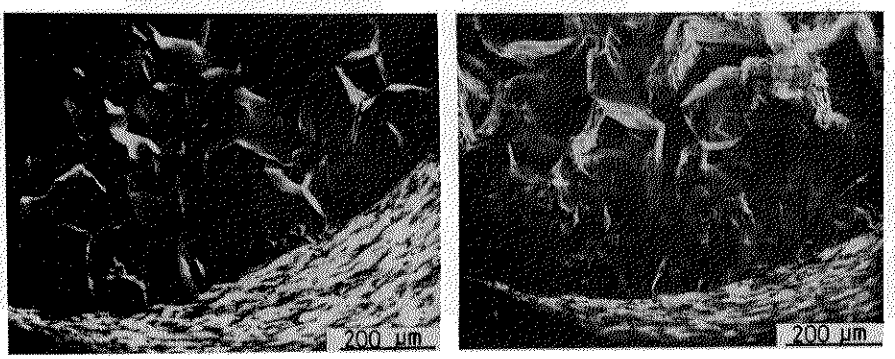

Fig. 3: Fatigue fracture surface of shot peened specimens.
a) in hydrogen b) in argon

8

Peen forming
Grenaillage de formage
Kugelstrahl – Umformen

KUGELSTRAHL – UMFORMEN – EIN FLEXIBLES UMFORMVERFAHREN,
R KOPP & K P HORNAUER

H O Fuchs

What is the (highest) Almen intensity used for the severe forming (of tubes)?

R Kopp

Wir haben keine Almenwerte parallel gefahren.

H O Fuchs

Do you know of any detrimental effects of the tensile self stresses which you showed?

R Kopp

Spannungsriss korrosion - Versuche bei vergleichbaren Spannungen verliefen positiv.

INVESTIGATIONS ON PEEN FORMING
K KONDO, S TSUZUKI & A KATO

H O Fuchs

Regarding less roughness with larger balls: This is commonly found if the EFFECT is held CONSTANT (bulge height, Almen intensity, depth of compressive stress etc ...). Only if VELOCITY (or air pressure or drop height) is CONSTANT we see more roughness with larger balls. It seems to me that plotting for constant velocity is rather misleading and plotting for constant Almen intensity is more instructive.

K Kondo

We agree with your remarks because Almen intensity is a suitable and standardized test value which represents the inclusive forming effect. We used bulge height or peening energy as a simple parameter to summarize a large volume of basic test data.

And as you indicated in your remarks bulge height is thought to represent nearly the same inclusive forming effect.

R S Livesey

1. For reference purposes a method for curvature measurement utilising thin cylinders has been used now for some 15 to 20 years.

2. When analysing the unusual effects of reversed curvature, account must be taken of the residual impulse energy of the shot which can force the material to change its curvature within a fixed frame and keep its new shape due to the revised elastic stresses within an expanded plastic surface. The new shape will then tend to hold its position owing to the residual compressive stresses acting about the polar neutral axis of the complete shape rather than about the basic neutral axis of a discreet element of the material.

K Kondo

Thank you for your remarks.

BALL-DROP PLATE BENDING: AN EXPERIMENTAL STUDY OF SOME OF ITS PROCESS VARIABLES

S K GHOSH, W JOHNSON & A G MAMMALLS

J F Loersch

Why are your saturation curves (Figure 5) vs. total weight dropped indicate a straight line function? This does not appear to me to be a normal situation in shot peening.

S K Ghosh

A saturation curve has both a straight portion where the rate of increase in the curvature of workpiece is proportional to the total weight of balls dropped, and a curved portion which indicates the initiation of the saturation phenomenon. In the present investigation, the experiments on (soft) ductile materials had to be discontinued almost immediately after the attainment of this "straight line" behaviour, because further drop of balls gave rise to defects such as dimples, intense local thinning and cracks, with shot sometimes producing holes through the sheet; the associated curvature does also reverse; at least, in the central region of the workpiece. In the theoretical sense, therefore, we have not arrived at near the saturation or "curved" behaviour.