Office translation

Material Testing Laboratory
of the State of Brandenburg -
Instructed to perform material
testing for the state Berlin

Examination Report

No. 1.1/00/3669

2 copies

Client	TOP STORY Filmproduktion GmbH Mrs. Jutta Rabe August-Bebel-Straße 26-53 14482 Potsdam
Contents	Material examination of a part of the starboard front bulkhead of the ferry "Estonia" in order to prove mechanically caused structure deformations additional examinations as to order 1.3/00/3664.

Instructions receivedRef.	19.09.2000
Instruction entry	19.09.2000
Material received	01.09.2000
Material delivered by	client
Material cut off by	- " -
Time period of examination	10.10.2000 to 26.10.2000

1. Contents of Instructions

The supplied part of the starboard front bulkhead of the ferry "Estonia" was - according to agreement - examined to prove structural changes caused by detonation and to verify the results of order no. 1.3/00/3664. The following examinations were performed:

- Scanning electron microscope (SEM) examination
- Metallographical examinations
- Micro hardness process measurements
- Examination report

2. Statements Concerning the Objects to be Examined

2.1 Object to be examined

The triangular steel sample of the starboard front bulkhead has according to clients two sides (cathedes) which are fracture edges and one side (hypotenuse) which was flame-cut during cutting off of the sample. The fracture edges and the parts of the surfaces are corroded. The area marked side 1 shows besides red paint remains also partly broken parts of the white top layer. This side is according to clients the outside of the bulkhead. The area marked side 2 is, besides the mentioned corroded parts, exclusively covered by a layer of paint initially white. (Pictures to be found in examination report 1.3/00/3664.) The two fracture edges of the steel sample were marked side 3 and side 4 (sample plan see page 9). The fracture edges are slanted. At side 3 the slope points to the outside, at side 4 to the inside of the bulkhead.

For the additional examinations within the range of this order, a specimen, viz. GO22 from order 1.3/00/3664 was used. Four specimens for cross micro-sections and longitudinal micro-sections have been taken out of this part sample.

The part samples marked No. 1 and No. 2 on the specimen plan have been handed over to clients for their further disposal and have not been the subject of the examination by the MPA. The part samples marked 3, 6, 9 and 10 have been the subject of order 1.3/00/3664. The part samples Nos. 4, 5, 7 and 8 are the subject of these examinations.

2.2 Preparations of Specimen

After the drawing up of a sample plan macroscopic overview photos were made (see examination report 1.3/00/3664).

The complete sample plan is show on picture 1 and Table 1.

In order to carry out the additional examinations 4 specimens each were micro cut out in longitudinal and in transverse direction for the metallographic examination and furthermore, embedded, treated and structured. The metallographically treated micro sections were used for the micro-hardening development measurements. For SEM examinations the metallographically treated surface of specimen GO 22 from the order 1.3/00/3664 was applied. The micro section was goldized prior to the examination.

Table 1: Distribution of samples/specimens with markings.

Run. No.	Mark of specimen Client	Mark of specimen by MPA		Type of specimen	Remarks
		Part sample no.	Specimen no.		
1		3	1.3/00/3664 GO 22	micro section	SEM topography
2		4	1.1/00/3669 GO 11	micro section parallel to fracture edge	structure side 3, fracture edge
3		4	1.1/00/3669 GO 12	micro section trans-verse to fracture edge	structure side 3, fracture edge
4		4	1.1/00/3669 HMV 012	at micro section GO 12	micro-hardening process
5		5	1.1/00/3669 GO 21	micro section parallel to fracture edge	structure, side 3, fracture edge
6		5	1.1/00/3669 GO 22	micro section trans-verse to fracture edge	structure, side 3, fracture edge
7		5	1.1/00/3669 HMV 022	at micro section 022	micro-hardening process
8		7	1.1/00/3669 GO 31	micro section parallel to fracture edge	structure, side 4, fracture edge

9		7	1.1/00/3669 GO 32	micro section transverse to fracture edge	structure, side 4, fracture edge
10		7	1.1/00/3669 HMV 032	at micro section GO 32	micro-hardening process
11		8	1.1/00/3669 GO 41	micro section parallel to fracture edge	structure, side 4, fracture edge
12		8	1.1/00/3669 GO 42	micro section transverse to fracture edge	structure, side 4, fracture edge
13		8	1.1/00/3669 HMV 042	at micro section GO 42	micro-hardening process

3. Examination carried out and Results

3.1 SEM Examinations

Examination technique : Topographic and analytic examinations of a metallographically treated surface

Examination installation : SEM digital scanning microscope DSM 940 A of Messrs. CARL ZEISS OBERKOCHEN with EDX set of Messrs. LINK/OXFORD INSTRUMENTS LTD.

During the examination of specimen GO 22 of order 1.3/00/3664 (picture 32) lines became visible, which allowed the assumption that these could be internal cracks.

It has thus been the aim of the topographic examination to prove internal cracks in this specimen and to demonstrate the changes of the perlite grain.

Examination results

The metallographically treated surface was examined intensively for possible micro cracks. The suspicion of internal cracks could not be confirmed. In order to support the light microscopic evaluation of the changes of the perlite grains due to detonation SEM picture were made from some perlite grains which are shown on pictures 2 to 7.

Beside the areas with still distinct lamellar structure of the cementite lamellas (pictures 2 and 3) there are areas with severely deformed lamellas (picture 4 and 5) respectively with destroyed lamellas (pictures 4 to 7). The typical

rounded grain form of perlite is most extensively changed respectively does no more exist.

The results correlate with the metallographic examinations of specimen GO 22 of order 1.3/00/3664. These plastic deformations in the micro area do indicate an extreme striking strain, as occurs in a detonation.

3.2 Structure Examination

3.2.1 Metallographic examination

Examination technique	:	Metallographic preparation, etching technique and light microscope
Examination installation	:	Automatic polishing set TF 250 JEAN WIRTZ, stereo-microscope CZ JENA GMBH, Camera uplight microscope Neophat 32 CZ JENA GMBH, Picture analysis system Imtron 2000 Messrs. IMTRONIK GMBH

Examination Results:

In order to verify the results obtained from order 1.3/00/3664 specimen were taken from the fracture area near the site where specimen 1.3/00/3664 GO22 was taken, which clearly showed distinct influence of force. These new specimens were taken from side 3 and side 4 for in total 4 transverse and longitudinal micro sections.

The longitudinal micro sections are running through the fracture edge while the micro cross-sections are located 0.5 mm away from the fracture edge.

The metallographic examination of specimen 1.1/00/3669 GO11 and 1.1/00/3669 GO12 (picture 1, sample cut no. 4) show a fine, recrystallined, slightly lamellar ferrite, perlite structure with manganese sulphide slag and secondary cementite precipitations along the grain edges (pictures 8-11). The structure mainly consists of ferrite. Inside the perlite grain changes of the cementite lamellars are visible. The striped lamellar structure is clearly disturbed (pictures 9, 11). On examining specimen 1.1/00/3669 GO21 and

1.1/00/3669 GO22 (picture 1, sample cut 5) changes were recognized which indicate higher strain.

The systematic arrangement of the structural parts is changed (pictures 12-17). Inside the ferrite grain sliding planes and shear bands are visible (pictures 16, 17).

These changes can also be seen on specimen 1.1/00/3669 GO31 and 1.1/00/3669 GO32 (picture 1, cut sample no. 7), 1.1/00/3669 GO41 and 1.1/00/3669 GO42 (picture 1, cut sample no. 8 – pictures 18-26). The disturbed lamellar arrangement of the perlite grains, as well as the existence of sliding planes and parallel shear bands, lead to the conclusion that there must have been stronger mechanical strain at a very high deformation velocity, which is typical for detonations (pictures 19, 21, 22, 24, 26).

3.3.2 Micro hardness measurement

Examination technique	:	Metallographic treatment, micro-hardening measurement
Examination installation	:	Micro-hardening examination set, computer controlled HMV2000, SHIMADZU

Examination Results:

The hardness measurements were performed at the metallographic longitudinal micro sections from the fracture edge to the core of the specimens 1.1/00/3669 GO12, 1.1/00/3669 GO22, 1.1/00/3669 GO32 and 1.1/00/3669 GO42.

For a better recording of the hardness in the edge-near area the micro-hardness measurements were carried out by HV 0.05 (small indentation diagonal). In the immediate vicinity of the fracture surface the measure point 1 is always situated. The measured distance was always 0.5 mm.

The results of the measurements are shown in tables 2, 3, 4 and 5 (pages 22-25).

The hardness values of steel St 37-2, which was used for comparison purposes, was found to be in the range of HV 105 to HV 145 after the change of the tensile strength Rm into Vickers HV.

The lowest hardness values of the examined specimens, which were measured at the areas farthest away from the fracture edge, were found to be HV 328 to HV 384. They show a clear increase of hardness and thus a substantial hardening of the material even 7.5 mm distant from the fracture edge (change of displacement density).

The variations of the hardness values (table 2-5) are due to the small force (small indentation diagonal) on the recording of small structure areas, which differ from each other by their hardness (soft ferrite, hard perlite).

4. Summary of Results

In order to verify the results obtained by order 1.3/00/3664, additional specimens were taken from the fracture area near the distinctly strained specimen 1.3/00/3664 GO22 from the part of the starboard front bulkhead.

The metallographic examinations revealed a fine, recrystallined, slightly lamellar ferrite, perlite structure with manganese sulphide slag and secondary cementite precipitations along the grain edges. The main part of the structure is ferrite. Inside the perlite grain changes of the cementite lamellars are visible. The striped lamellar build-up is distinctly disturbed. In 3 out of 4 of the metallographically examined specimens the systematic arrangement of the structure parts is changed.

Inside the perlite grain sliding planes and shear bands are recognizable.

The disturbed lamellar build-up of the perlite grain as well as the presence of sliding planes and shear bands permit to conclude a heavier strain at very high deformation velocities.

The topographic examination by means of the scanning electronic microscope (SEM) show in the perlite grain in addition to areas with still distinct lamellar structure of the cementite lamellars, areas in which the lamellars are heavily deformed respectively destroyed. The typical rounded grain shape of the perlite has been changed beyond recognition. The metallographically treated surface was examined intensively for possible micro cracks. The suspicion of internal cracks was not confirmed.

The hardness values obtained during micro hardness measurements have been compared with the hardness values of steel St 37-2. In accordance with the established change of the tensile strength Rm of the steel St 37-2 the hardness values should be in the range of HV 105 – HV 145. The lowest hardness value of the examined specimen is HV 328. This indicates a strong hardening.

5. Summary of Both Examination Results and Conclusions (orders 1.3/00/3664 and 1.1/00/3669)

On consideration of all the examinations carried out the highest strains recognisable by the change of the structural parts in the above explained way, has been determined at specimen 1.3/00/3664 GO22.

All the other micro-sections do support these results.

They do not, however, show the strong changes as e.g. the wavy change of the structure in the areas near the fracture and the destruction of the initial structure arrangement.

The plastic changes in the micro area, indicating an extremely strong shock effect, such as occurs during detonations, are recognisable in all specimens.

A general characteristic for a detonation is the destruction of the shell type build-up of the perlite. In the pictures made by SEM it is apparent that the cementite of the perlite did not coagulate, which would have indicated the influence of heat alone, but the lamellar structure was changed beyond recognition by mechanical strain. Internal cracks which are also characteristic of shocks from strain by detonations could not be proved by the topographic examinations performed.

Also the increase of hardness indicates a hardening of the material which also appears during detonations.

The results obtained do allow the conclusion that the positions most affected by the detonation was in another area of the damaged material.

In the following all the examination results are outlined again, which, according to our experience, do occur when there has been a detonation:

- the appearance of parallel shear bands (Neumann bands)
- changes respectively destruction of the cementite lamellas in the perlite
- hardness increase
- plastic deformation in the micro area (wavy arrangement of the structure parts)

The characteristics, determined during the examinations, which are consistent with the effects of a detonation, allow the conclusion, that the deformation velocity in the material must also have been in the detonation range. It is not possible to state the actual speed because it depends on a number of unknown influence factors, as e.g. the extent of transmission losses. Its lower limit in the case of a detonation should be about 1000 m/sec.

Berlin, 24.11.2000

Signed by

Dr. Ing. H. Nega Dipl. Ing. H. Mettel

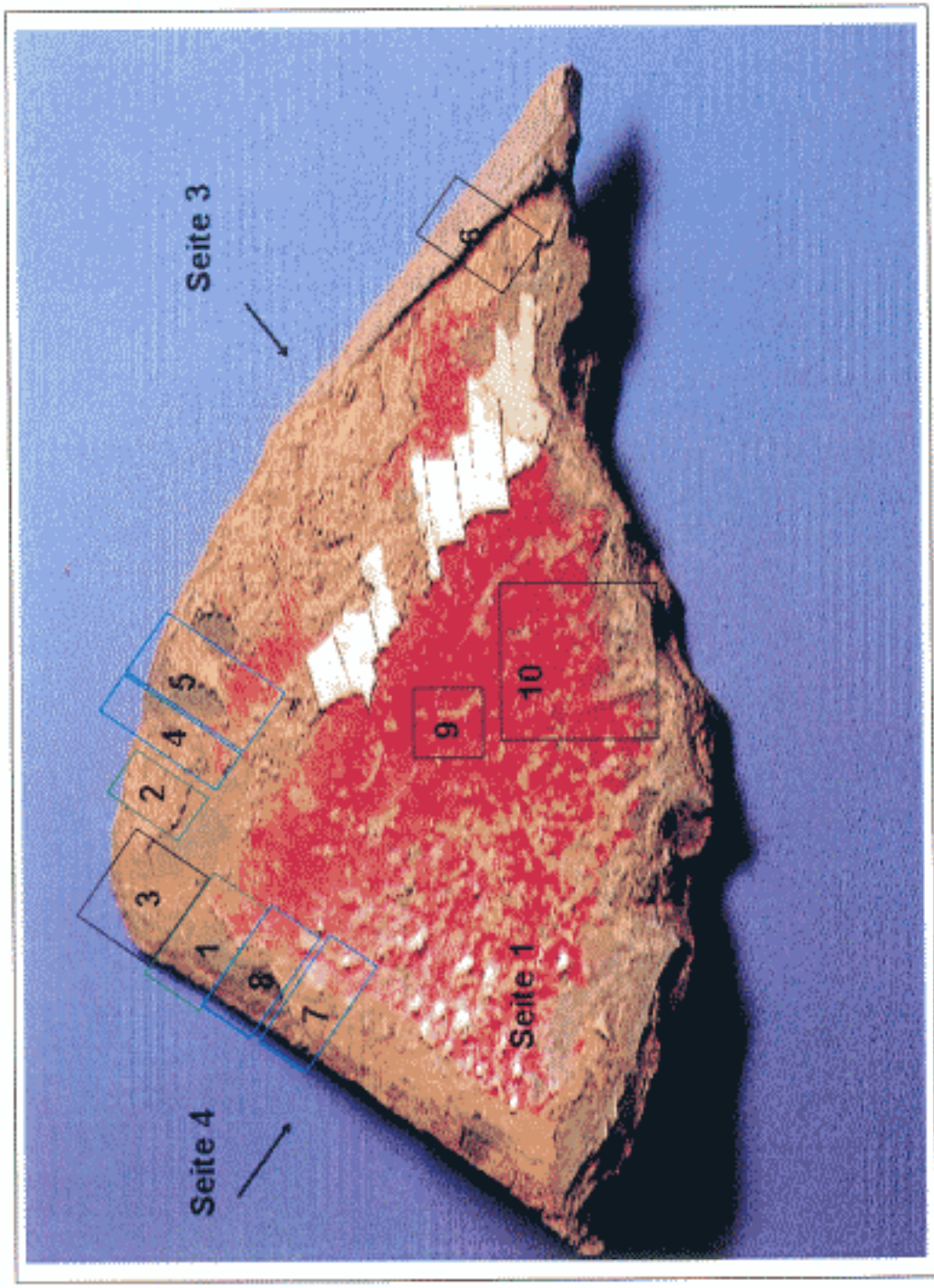


Bild 1 Probenplan, ca. 1:1, Aufteilung der Proben: Nr.: 1, Nr.: 2, Übergabe an den Auftraggeber
Nr.: 3, Nr.:6, Nr.: 9, Nr.: 10, MPA, Auftrag 1.3/00/3664
Nr.: 4, Nr.: 5, Nr.:7, Nr.: 8, MPA, Auftrag 1.1/00/3669

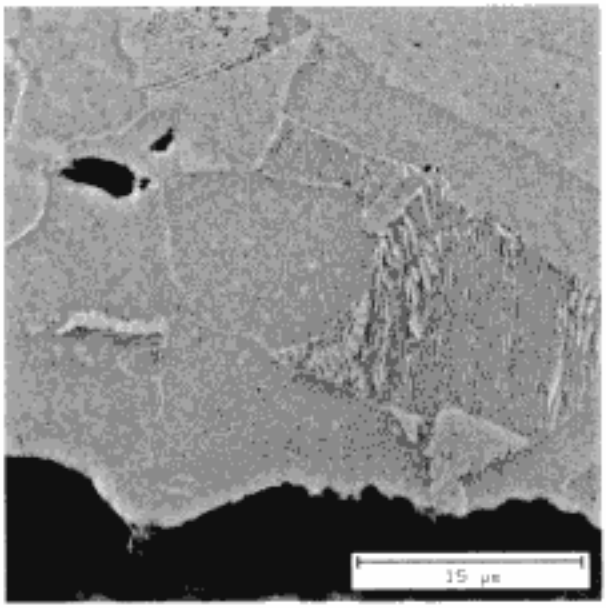


Bild 2 REM-Aufnahme der metallographisch bearbeiteten Fläche - Perlitkorn

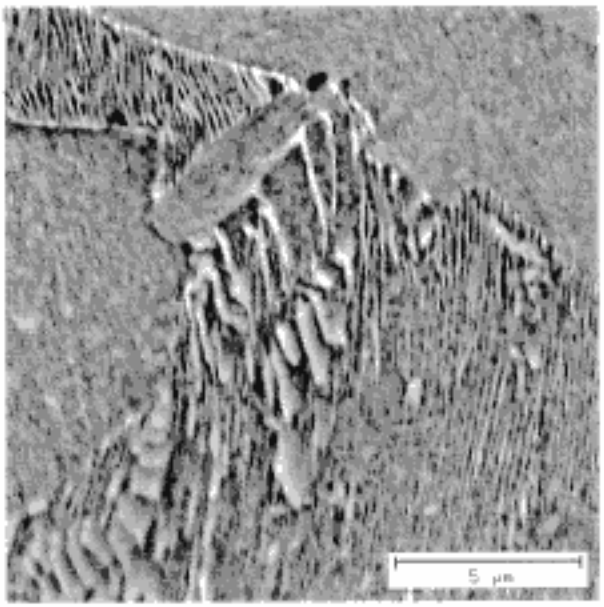


Bild 3 REM-Aufnahme der metallographisch bearbeiteten Fläche – Perlitkorn; Detail von Bild 2

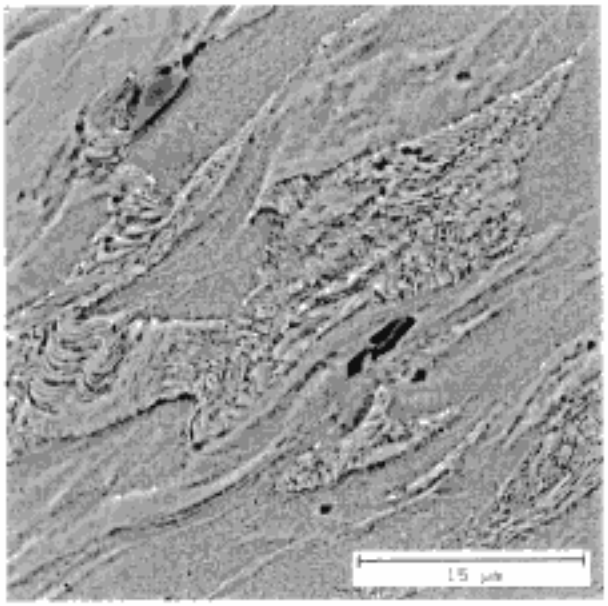


Bild 4 REM-Aufnahme der metallographisch bearbeiteten Fläche - Perlitkörner

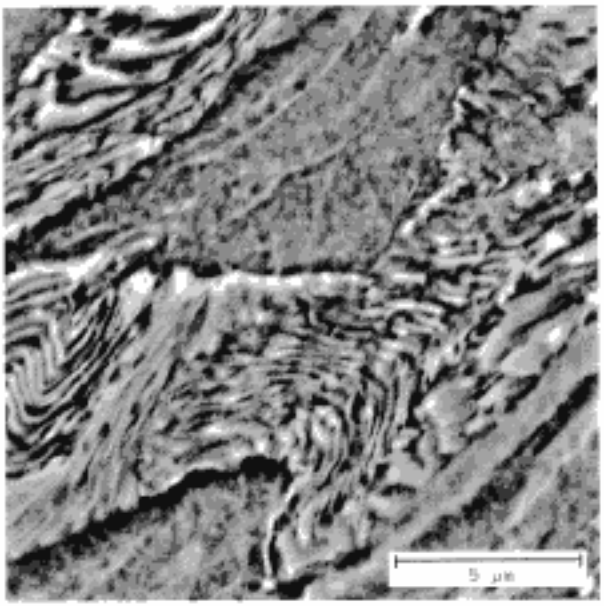
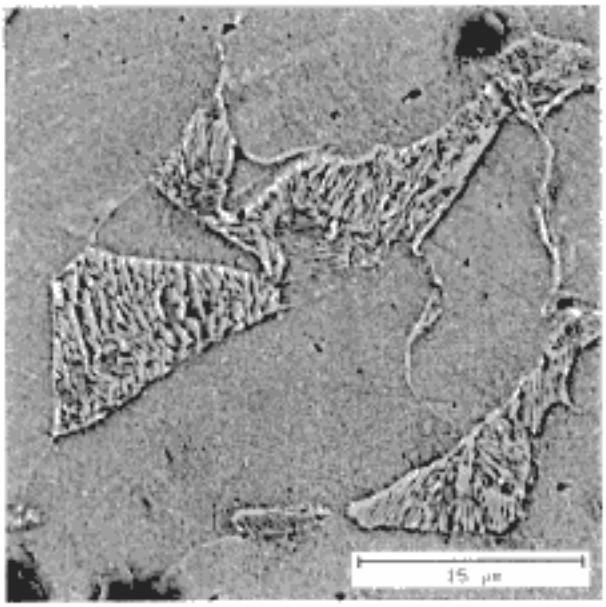


Bild 5 REM-Aufnahme der metallographisch bearbeiteten Fläche – Perlitkörner; Detail von Bild 4



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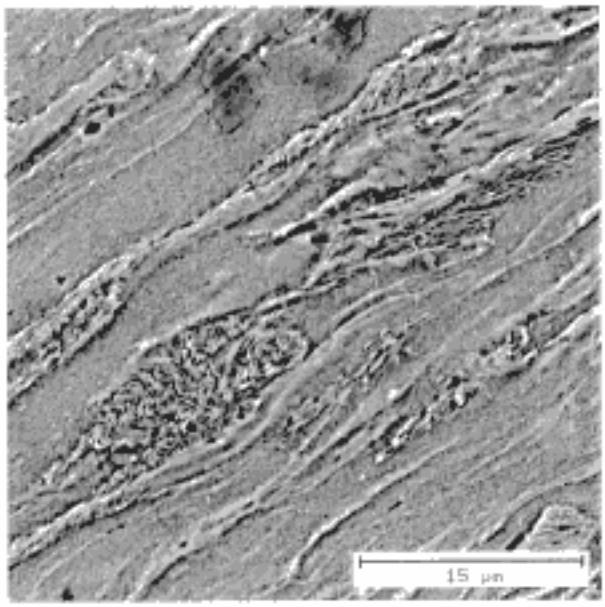
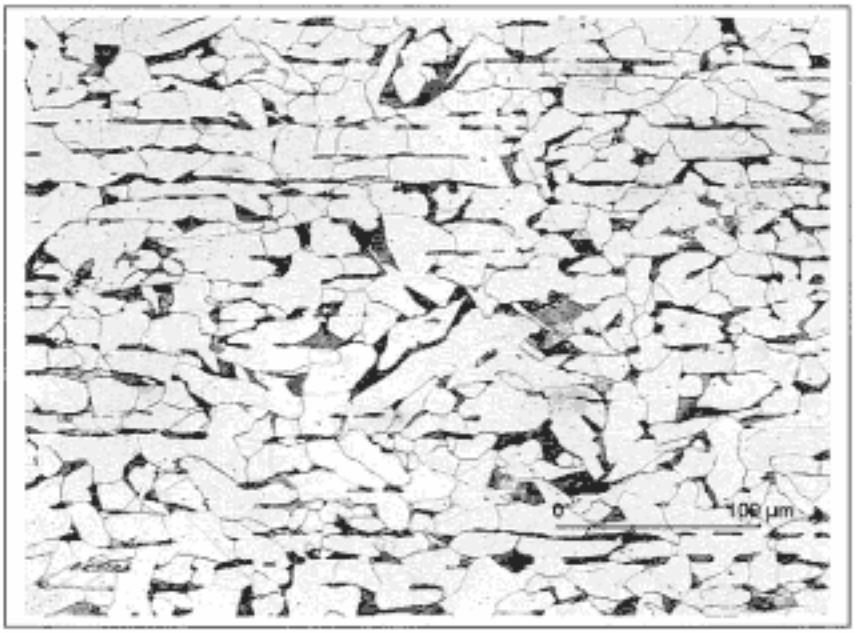


Bild 7 REM-Aufnahme der metallographisch bearbeiteten Fläche – Perlitkörner gerissen



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Probenplan Nr.: 4

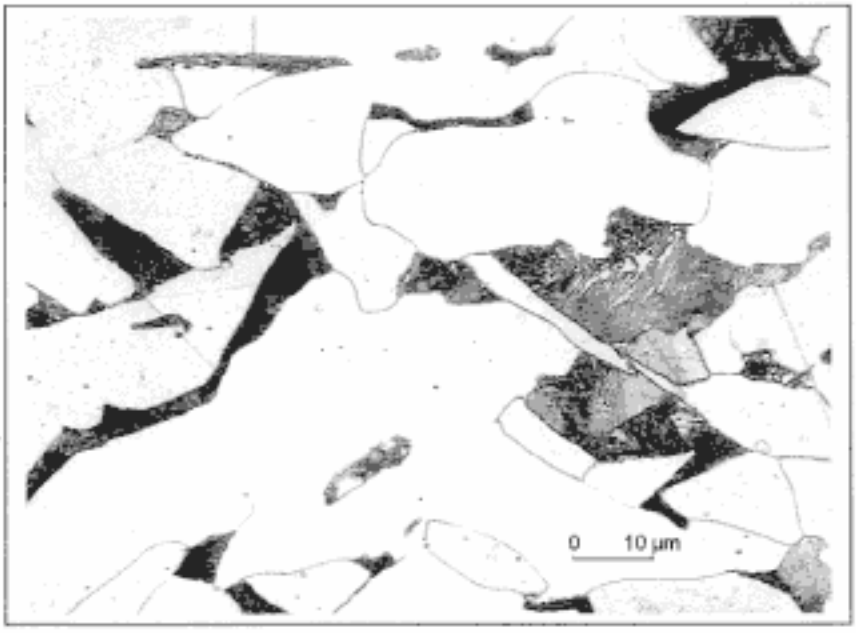
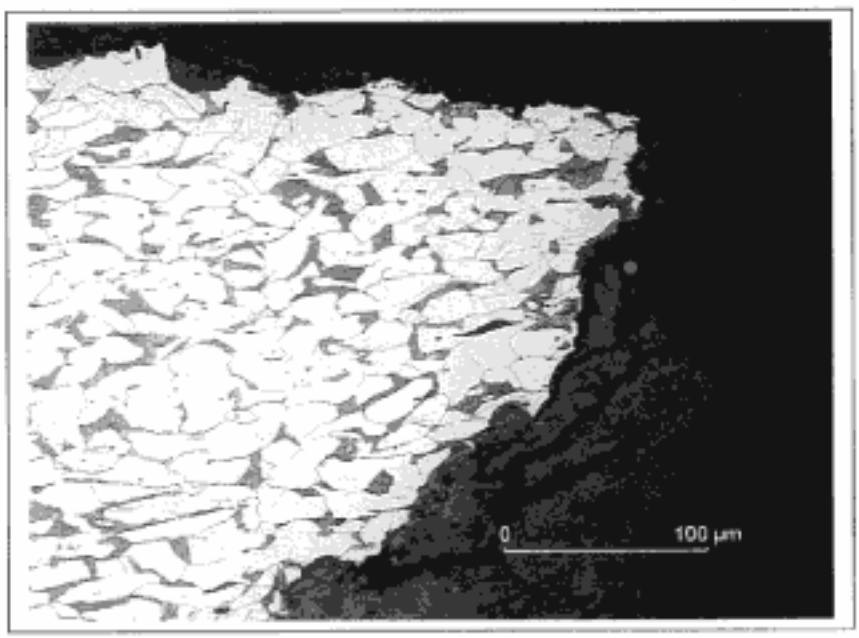


Bild 9 Probe 1.1/00/3669 G011
Ausschnitt aus Bild 8



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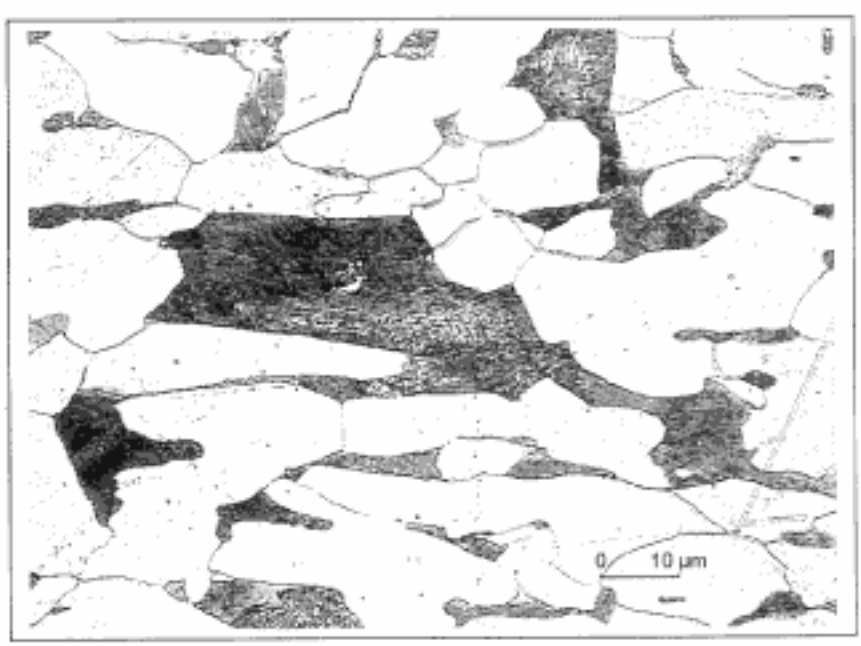

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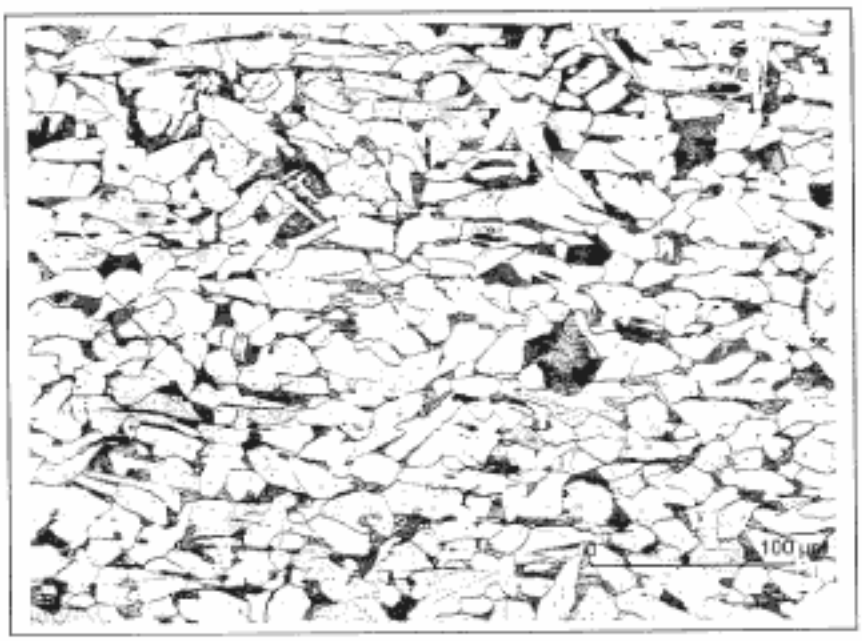
Ausschnitt aus Bild 10



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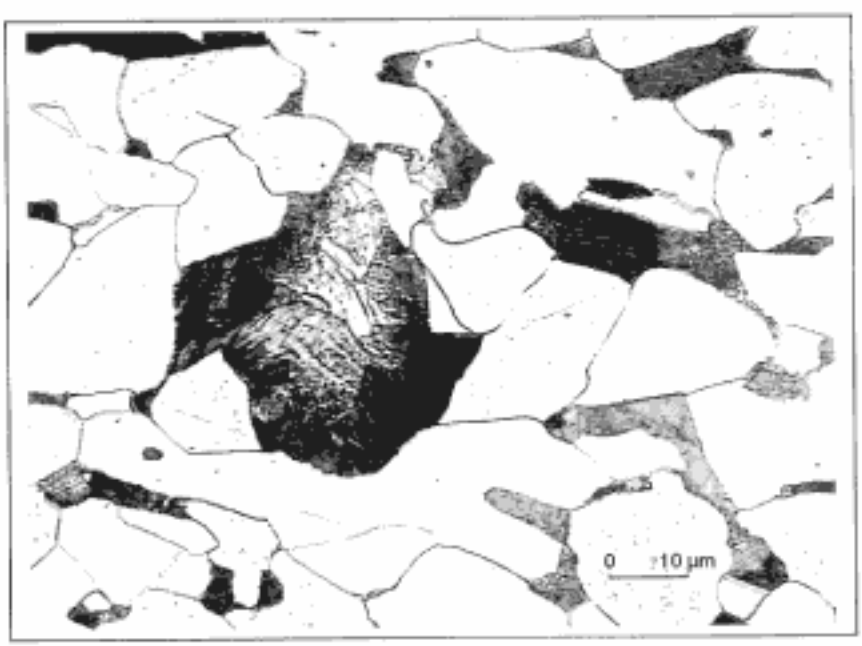

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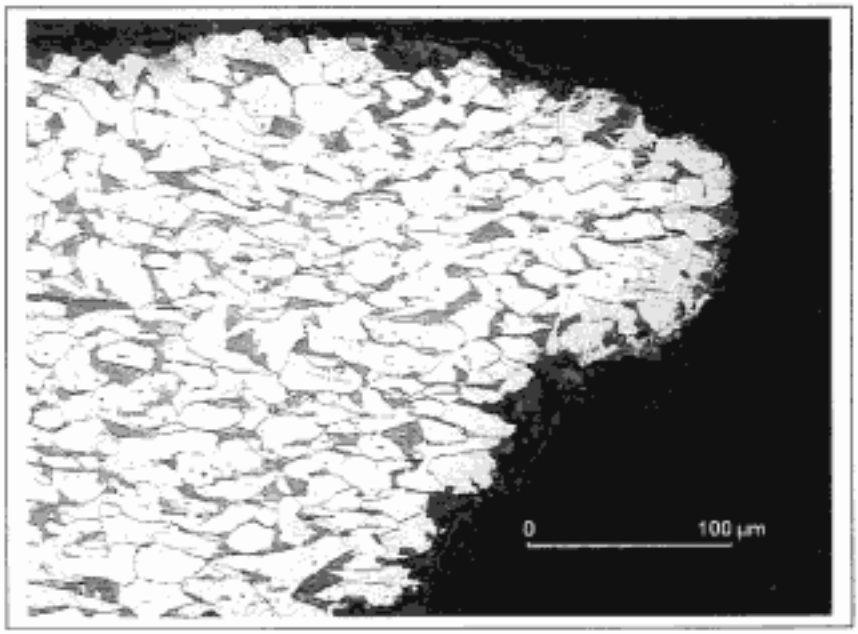

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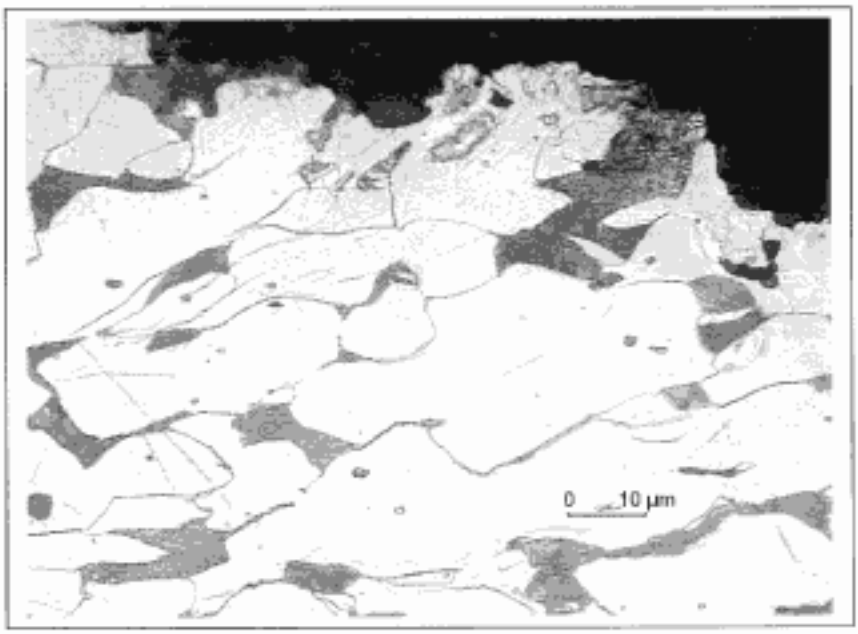

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Ausschnitt aus Bild 14

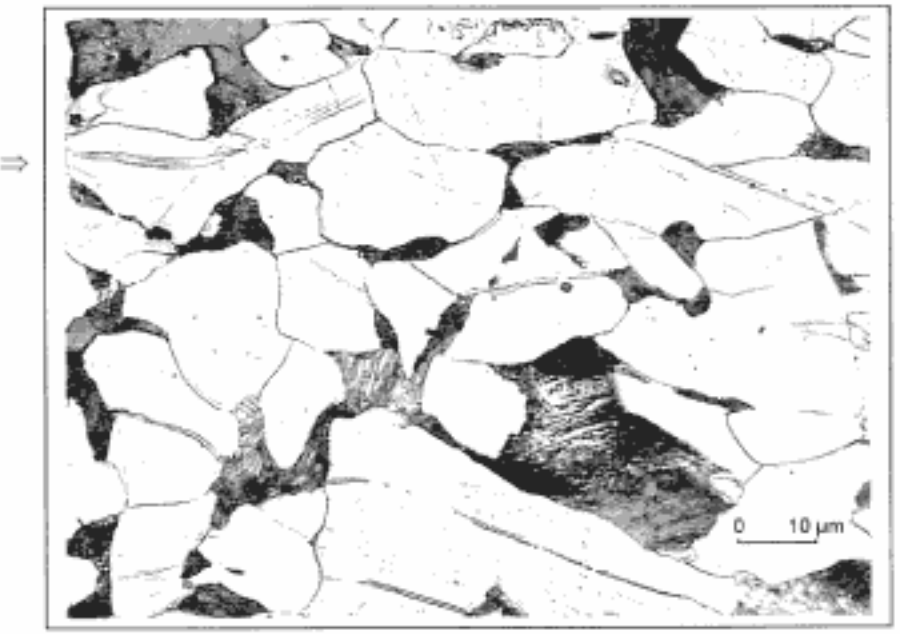

Bild 16 Probe 1.1/00/3669 G022
Ausschnitt aus Bild 14
⇒ Gleitebenen

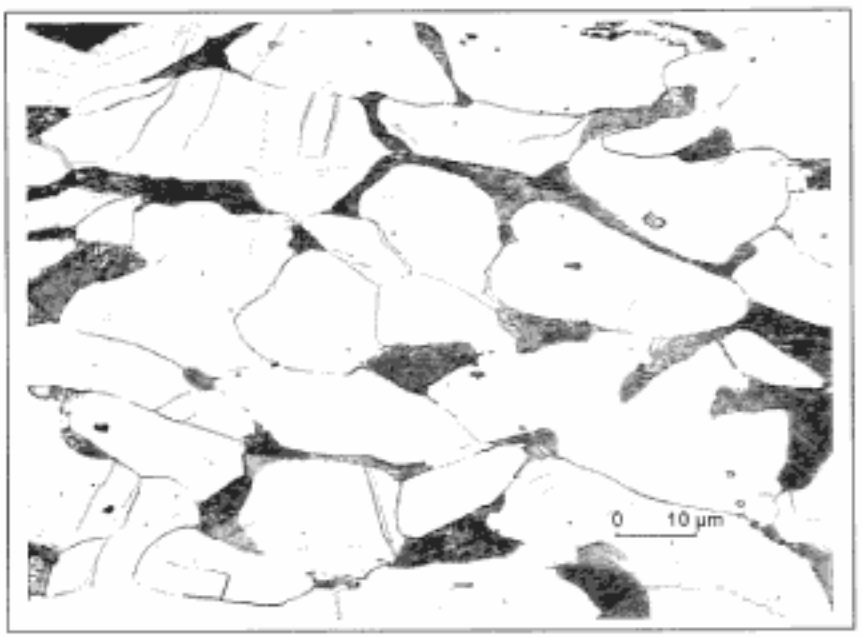

Bild 17 Probe 1.1 /00/3669 G022
Ausschnitt aus Bild 14
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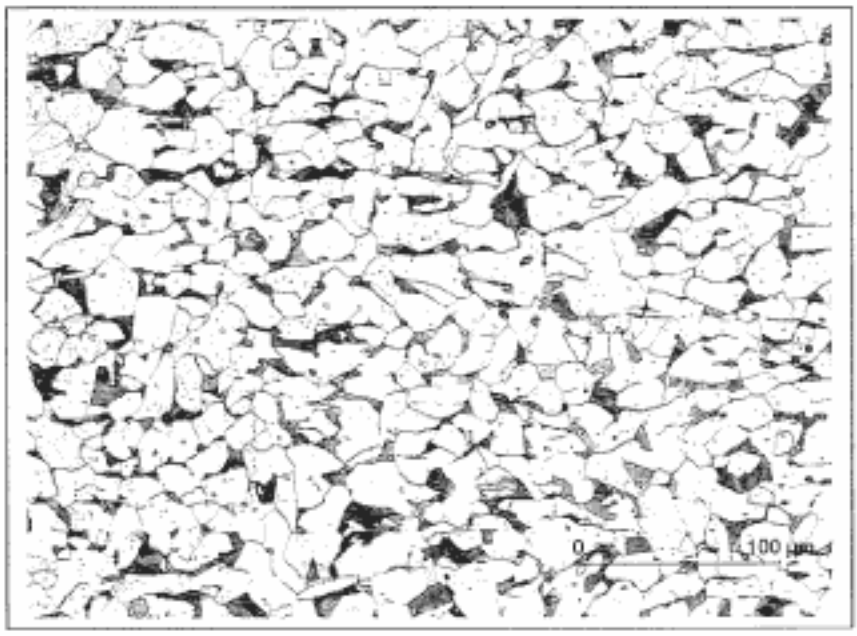

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Probenplan Nr.: 7

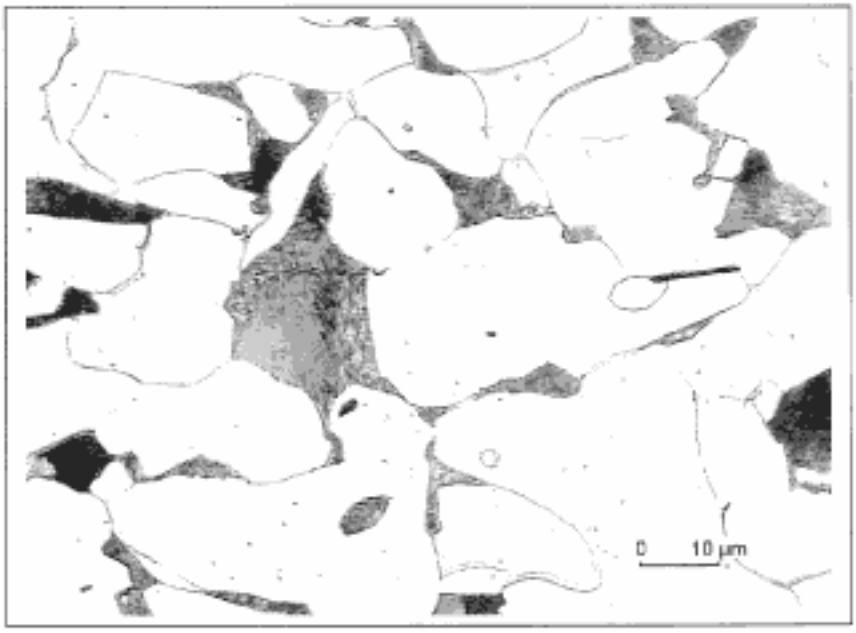

Bild 19 Probe 1.1/00/3669 G031
Ausschnitt aus Bild 18

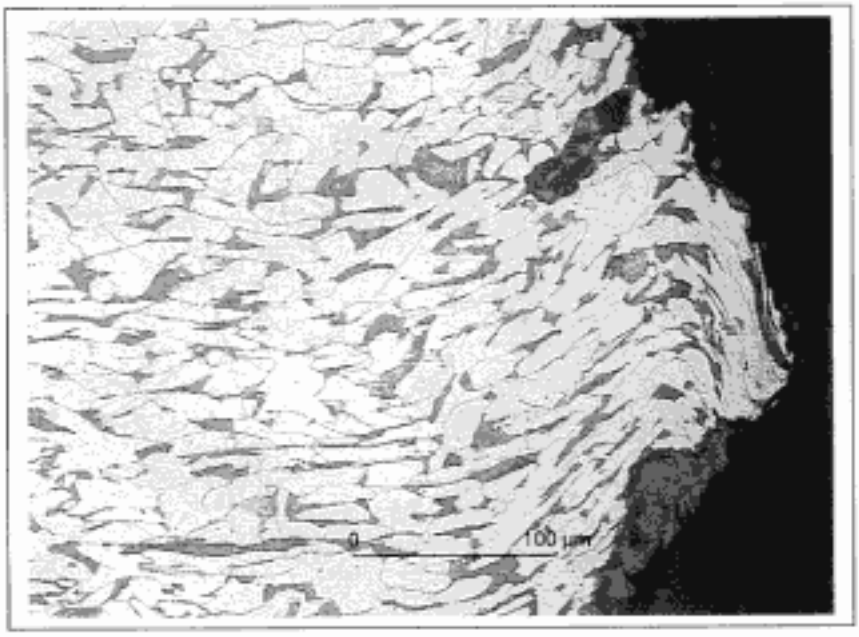

Bild 20 Probe 1.1/00/3669 G032
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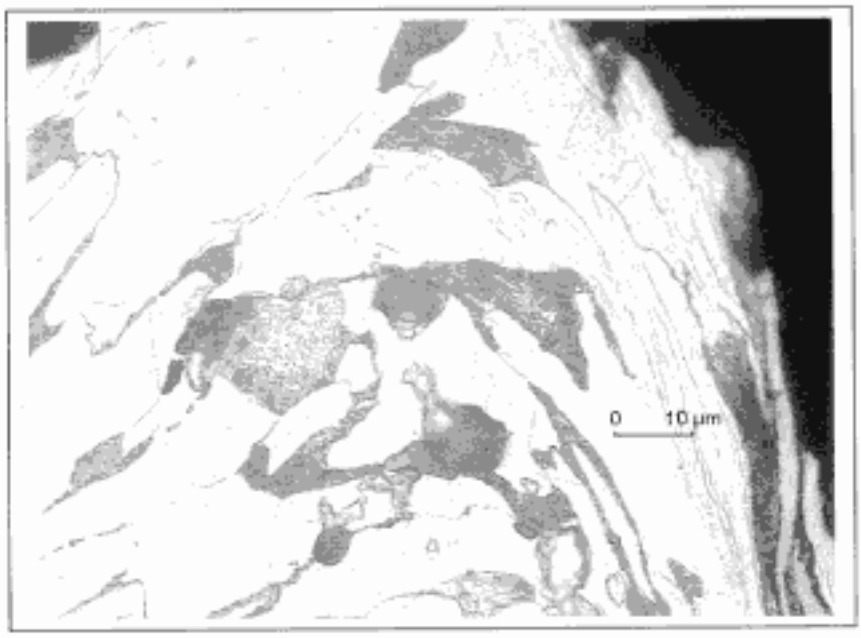

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Bild 21 Probe 1.1/00/3669 G032
Ausschnitt aus Bild 20
⇒ Gleitebenen

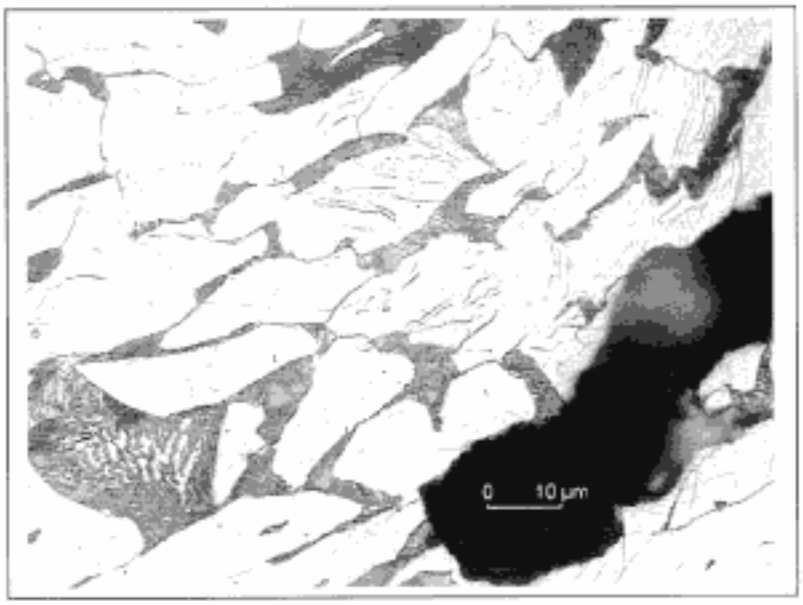


Bild 22 Probe 1.1/00/3669 G032
Ausschnitt aus Bild 20
Scherbänder

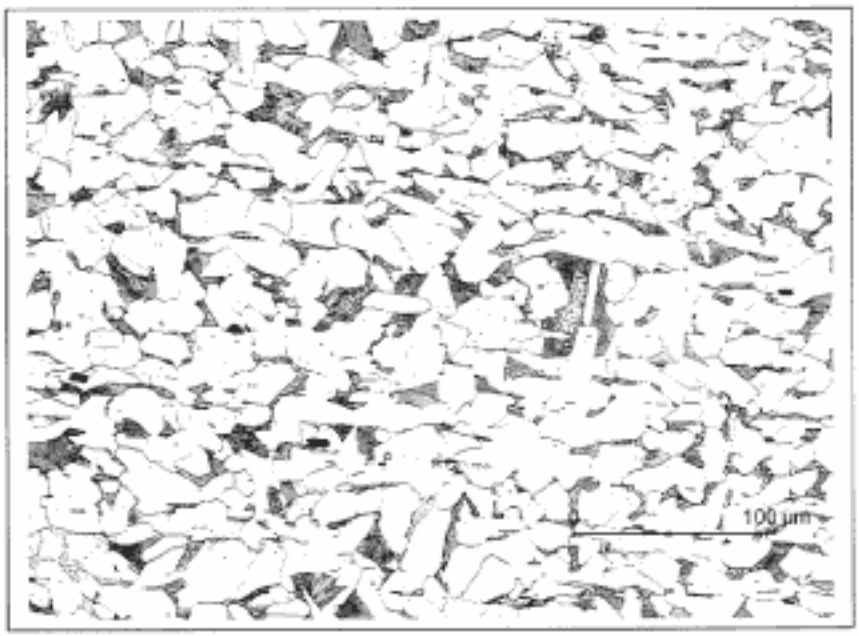
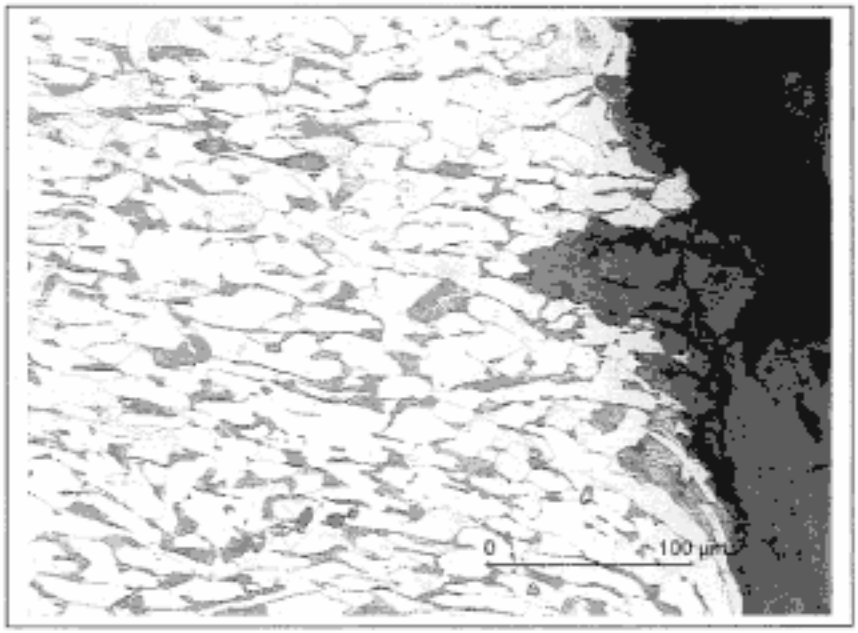


Bild 23 Probe 1.1/00/3669 G041
Probenplan Nr.: 8

Bild 24 Probe 1.1/00/3669 G041
Ausschnitt aus Bild 23



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Probenplan Nr.: 8

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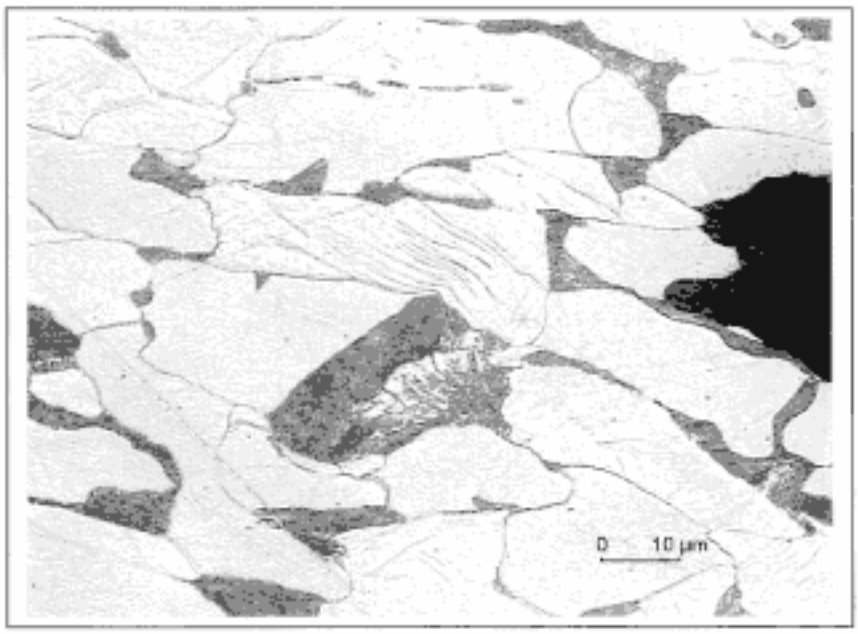

Bild 26 Probe 1.1/00/3669 G042
Ausschnitt aus Bild 26
⇒ Gleitebenen

Materialprüfungsamt
des Landes Brandenburg

Vickershärteprüfung
nachEN ISO 6507-1

Auftraggeber :	TOP STORY Filmproduktion GmbH
Auftrag :	1.1/00/3669
Datum :	26.10.2000

Prüfer:	Dipl. Ing. (FH) H. Mettel
Prüfmaschine:	Shimadzu HMV-2000
Prüfbereich:	HV 0,05
Werkstoff:	St

Probe / Schliff
3869 G012

Mittelwert	Min.	Max.	S-abw.
445	384	563	44

Nr.	x[mm]	y[mm]	d1[µm]	d2[µm]	HV
1	0,00	0,00	13,9	13,5	496
2	0,50	0,00	14,4	14,3	450
3	1,00	0,00	13,7	15,5	434
4	1,50	0,00	14,7	14,1	445
5	2,00	0,00	13,7	14,3	472
6	2,50	0,00	14,9	14,0	445
7	3,00	0,00	13,7	14,8	455
8	3,50	0,00	14,1	14,3	461
9	4,00	0,00	14,6	15,2	419
10	4,50	0,00	12,4	13,3	563
11	5,00	0,00	14,1	14,3	461
12	5,50	0,00	15,1	14,8	415
13	6,00	0,00	15,6	15,5	384
14	6,50	0,00	15,1	14,3	429
15	7,00	0,00	15,1	15,5	397
16	7,50	0,00	15,6	15,3	388

Tabelle 2 : Mikrohärteprüfung

Materialprüfungsamt
des Landes Brandenburg

Vickershärteprüfung
nach EN ISO 6507-1

Auftraggeber :	TOP STORY Filmproduktion GmbH
Auftrag :	1.1/00/3669
Datum :	26.10.2000

Prüfer:	Dipl. Ing. (FH) H. Mettel
Prüfmaschine:	Shimadzu HMV-2000
Prüfbereich:	HV 0,05
Werkstoff:	St

Probe / Schliff
3669 G022

Mittelwert	Min.	Max.	S-abw.
443	341	528	46

Nr.	x[mm]	y[mm]	d1[µm]	d2[µm]	HV
1	0,00	0,00	14,1	13,5	490
2	0,50	0,00	14,4	13,5	478
3	1,00	0,00	14,4	15,3	419
4	1,50	0,00	16,3	16,7	341
5	2,00	0,00	14,9	14,3	434
6	2,50	0,00	15,1	13,3	461
7	3,00	0,00	13,9	15,2	439
8	3,50	0,00	15,6	14,0	424
9	4,00	0,00	14,6	15,3	415
10	4,50	0,00	15,1	15,5	397
11	5,00	0,00	13,4	13,5	515
12	5,50	0,00	14,6	14,1	450
13	6,00	0,00	14,9	15,3	405
14	6,50	0,00	13,1	13,5	528
15	7,00	0,00	14,6	14,1	450
16	7,50	0,00	13,4	15,8	434

Tabelle 3: Mikrohärteprüfung

Materialprüfungsamt
des Landes Brandenburg

Vickershärteprüfung
nach EN ISO 6507-1

Auftraggeber :	TOP STORY Filmproduktion GmbH
Auftrag :	1.1/00/3669
Datum :	26.10.2000

Prüfer:	Dipl. Ing. (FH) H. Mettel
Prüfmaschine:	Shimadzu HMV-2000
Prüfbereich:	HV 0,05
Werkstoff:	St

Probe / Schliff
3669 G032

Mittelwert	Min.	Max.	S-abw.
417	328	502	50

Nr.	x[mm]	y[mm]	d1[µm]	d2[µm]	HV
1	0,00	0,00	13,4	13,8	502
2	0,50	0,00	14,2	13,8	472
3	1,00	0,00	14,2	14,8	439
4	1,50	0,00	14,2	13,5	484
5	2,00	0,00	14,7	14,8	424
6	2,50	0,00	13,2	14,1	496
7	3,00	0,00	14,4	16,4	392
8	3,50	0,00	14,6	15,7	405
9	4,00	0,00	15,4	14,1	424
10	4,50	0,00	15,3	15,8	384
11	5,00	0,00	15,6	15,2	392
12	5,50	0,00	15,4	15,7	384
13	6,00	0,00	15,4	15,5	388
14	6,50	0,00	15,9	15,8	367
15	7,00	0,00	15,3	15,7	388
16	7,50	0,00	17,5	16,2	328

Tabelle 4: Mikrohärteprüfung

Materialprüfungsamt
des Landes Brandenburg

Vickershärteprüfung
nach EN ISO 6507-1

Auftraggeber :	TOP STORY Filmproduktion GmbH
Auftrag :	1.1/00/3669
Datum :	26.10.2000

Prüfer:	Dipl. Ing. (FH) H. Mettel
Prüfmaschine:	Shimadzu HMV-2000
Prüfbereich:	HV 0,05
Werkstoff:	St

Probe / Schliff
3669 G042

Mittelwert	Min.	Max.	S-abw.
442	356	549	60

Nr.	x[mm]	y[mm]	d1[µm]	d2[µm]	HV
1	0,00	0,00	12,5	13,5	549
2	0,50	0,00	14,2	13,5	484
3	1,00	0,00	14,2	14,0	466
4	1,50	0,00	14,7	14,1	445
5	2,00	0,00	14,7	13,8	455
6	2,50	0,00	14,2	13,6	478
7	3,00	0,00	13,6	14,5	472
8	3,50	0,00	14,9	15,0	415
9	4,00	0,00	13,4	14,6	472
10	4,50	0,00	13,9	14,8	450
11	5,00	0,00	15,9	16,4	356
12	5,50	0,00	13,4	12,9	535
13	6,00	0,00	15,1	15,0	410
14	6,50	0,00	15,8	16,4	360
15	7,00	0,00	15,9	16,0	363
16	7,50	0,00	16,3	15,8	360

Tabelle 5: Mikrohärteprüfung