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GZ.1093 / 009

Technische Universiteit Delft
Faculteit der Scheikundige Technologie en der Materiaalkunde
Vakgroep: Toepassingen van Materialen in Constructies
Sectie: Plasticiteit en Lange Duur Gedrag van Materialen

Relatie tussen de kerfslagwaarde en de
slagvastheid van een component in de praktijk

Appendices

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Delft, april 1993

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APPENDIX 1: SCHATTING VAN DE REKSNELHEID TIJDENS DRIE-PUNTSBUIGPROEVEN

Gebruikte symbolen:

f:	doorbuiging in het midden van het proefstuk
v:	belastingssnelheid
ϵ :	rek
L:	opspanlengte van het proefstuk
e:	uiterste vezelafstand ten opzichte van de neutrale lijn
K_t :	spanningsconcentratiefactor

Bij de berekening van de reksnelheden die tijdens dynamische driepuntsbuigproeven gehaald worden zijn een aantal aannamen gemaakt:

- Eventuele trillingen, veroorzaakt door traagheidseffecten als gevolg van de hoge snelheid waarmee het proefstuk geraakt wordt, hebben geen invloed op de spanningen die bij de kerf van het proefstuk optreden.
- Het proefstuk wordt beschouwd als een prismatische balk.
- Voor het berekenen van de initiële reksnelheid kunnen plastische effecten buiten beschouwing gelaten worden.

De doorbuiging in het midden van een ligger wordt gegeven door:

$$f = \frac{FL^3}{48EI} = \frac{ML^2}{12EI} \quad (1)$$

Tevens geldt:

$$\frac{M}{EI} = \frac{\epsilon}{e} \quad (2)$$

Combineren van (1) en (2) levert:

$$f = \frac{\epsilon L^2}{12e} \quad (3)$$

Voor de reksnelheid geldt dan:

$$\dot{\epsilon} = \frac{12e}{L^2} \dot{f} = \frac{12e}{L^2} v \quad (4)$$

De aanwezigheid van een kerf in een proefstuk werkt spanningsverhogend. De verhouding tussen de maximale spanningen die heersen in een gekerfd proefstuk (σ_{\max}) en een ongekerfd proefstuk (σ_{nom}) wordt de spanningsconcentratiefactor genoemd (K_t). De spanning wordt bij aanwezigheid van een kerf dus met een factor K_t verhoogd. Omdat de spanning evenredig is met de rek gaat formule (4) voor gekerfde proefstukken over in:

$$\dot{\epsilon} = K_t \frac{12e}{L^2} v \quad (5)$$

Wanneer formule (6) op de kerfslagproef volgens Charpy wordt toegepast geldt er:

$l=40$ mm,

$e=3$ mm,

$v=5000$ mm/s

$K_t=3.5$.

Voor de reksnelheid wordt dan gevonden:

$d\epsilon/dt=4 \cdot 10^2$ s⁻¹.

APPENDIX 2:GEGEVENS VAN DE GEBRUIKTE APPARATUUR

Valgewichtopstelling:
Dynatup 8000A met tup volgens Charpy norm

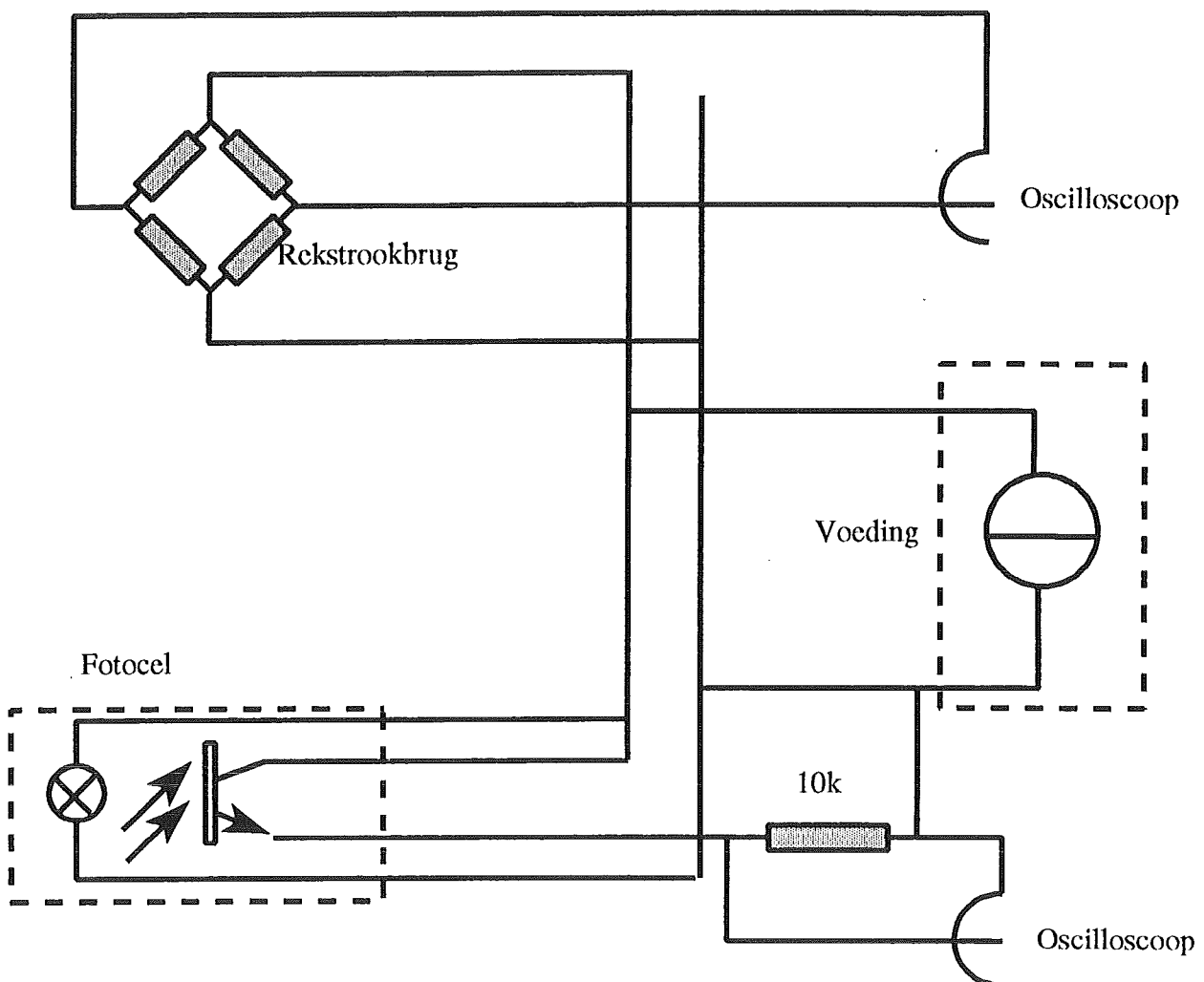
Digitale oscilloscoop:
Nicolet 410

Vermoeiingsbank:
Schenck Hydropuls PSB (25 ton)

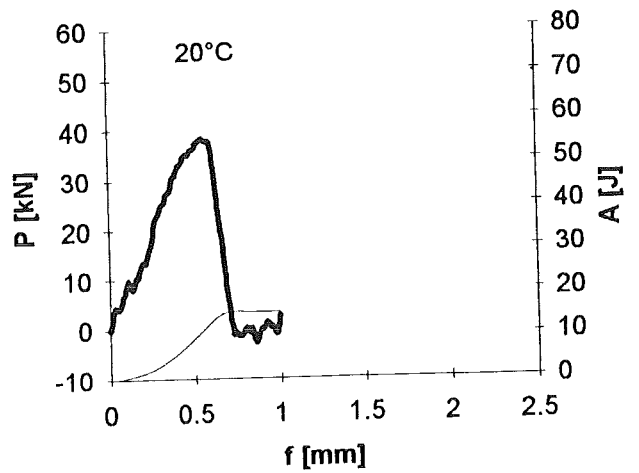
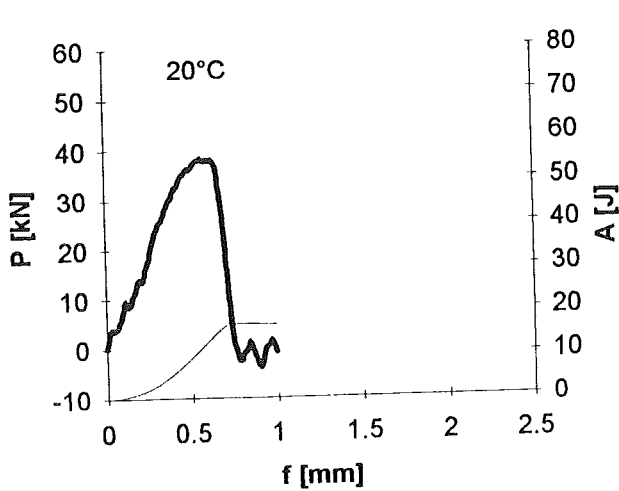
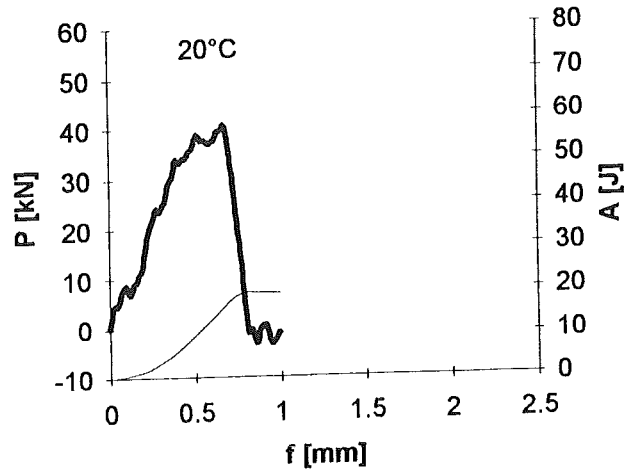
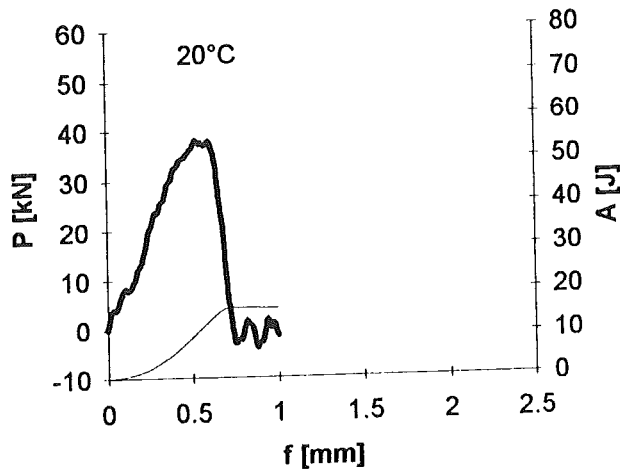
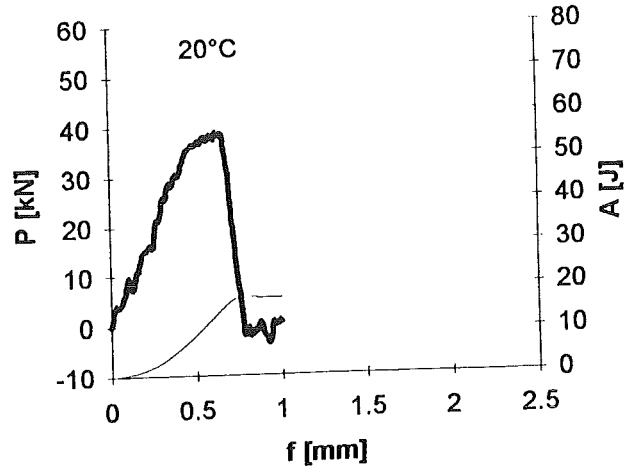
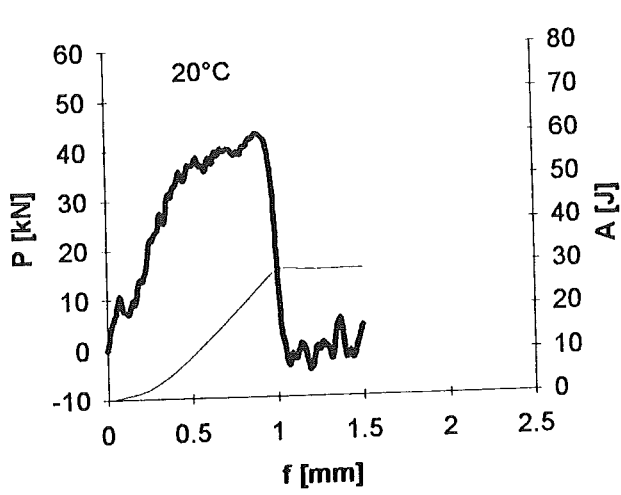
Kerfslaghamer:
MFL D-6707, PSW 300, Prüf und Meßsysteme GmbH, Schifferstadt

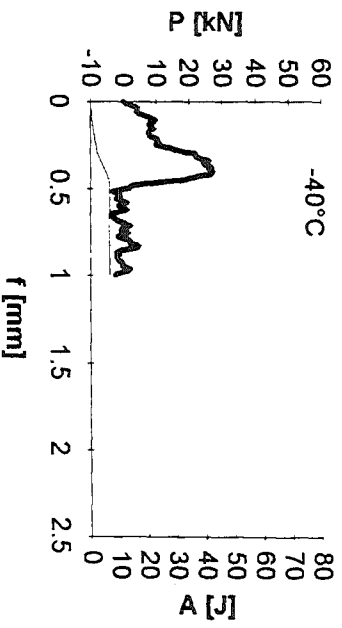
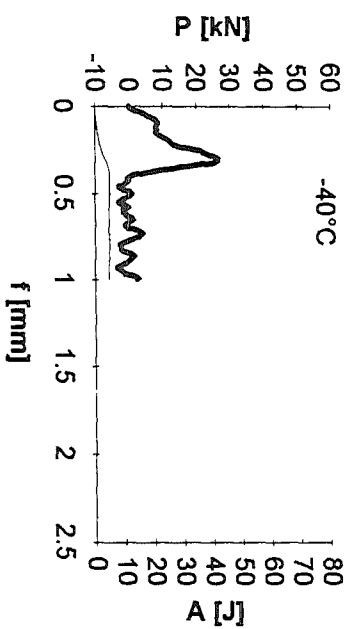
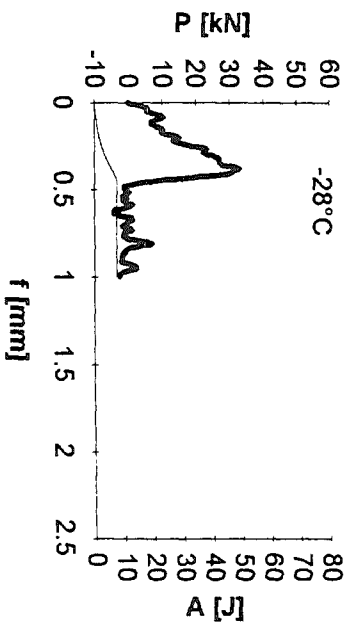
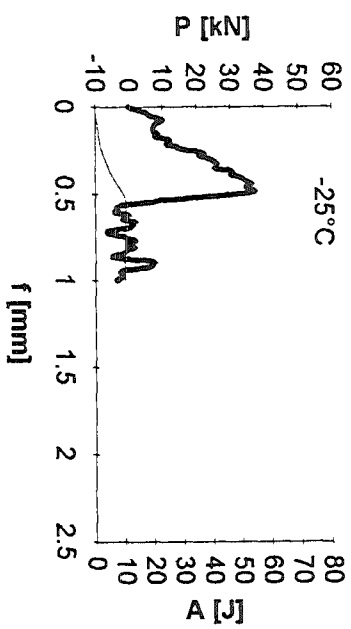
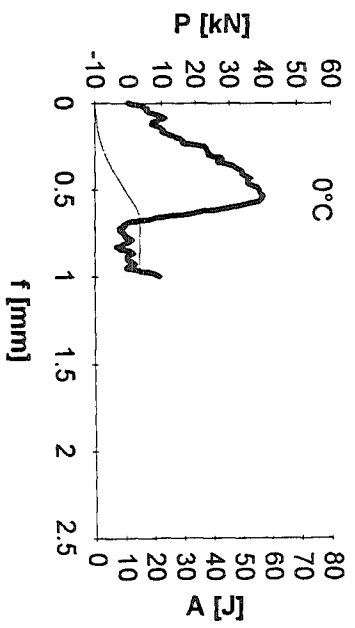
Transciënt recorder:
Nicolet Instr. Corp.

Electrisch aansluitschema van de valgewichtopstelling:



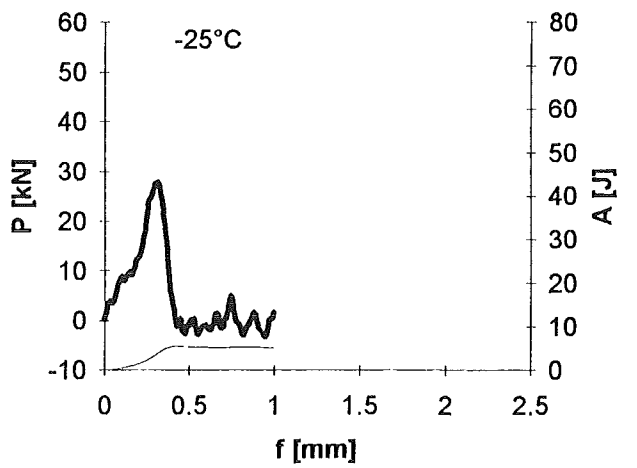
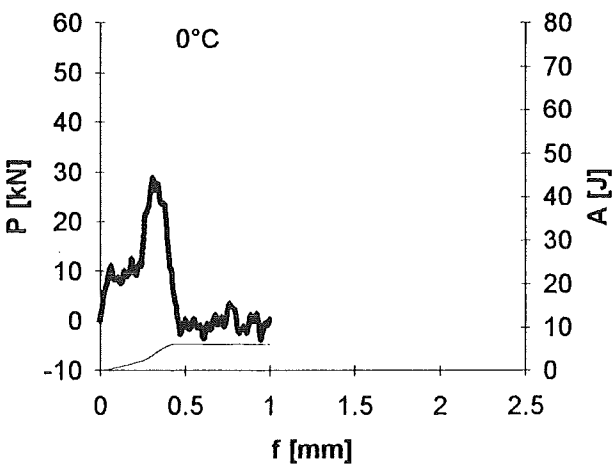
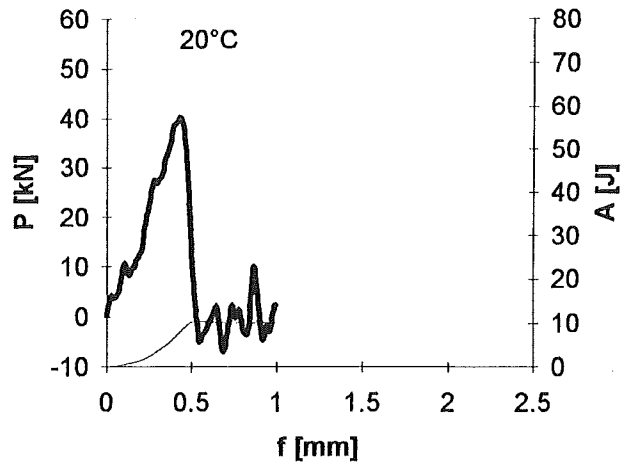
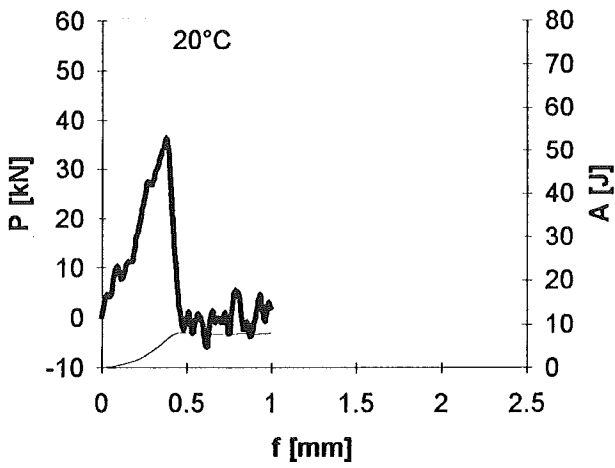
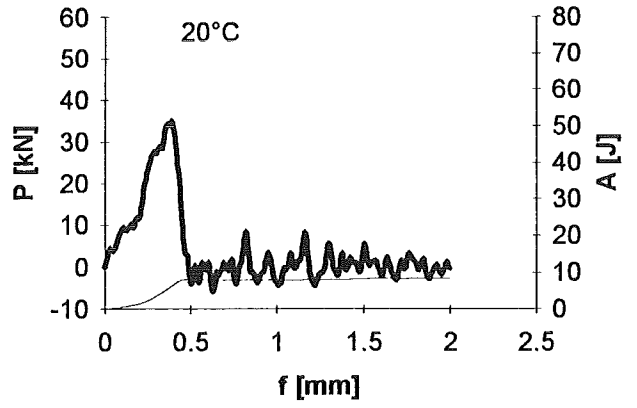
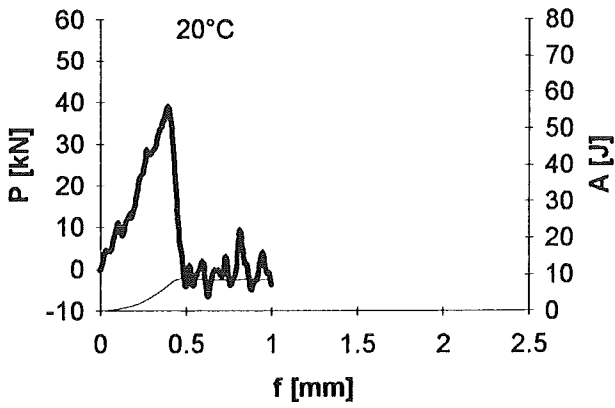
Appendix 3: Resultaten van valgewichtproeven
kracht en energie als functie van de doorbuiging bij verschillende temperaturen.
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proefstukken: U30mm
beproevingssnelheid: 3m/s

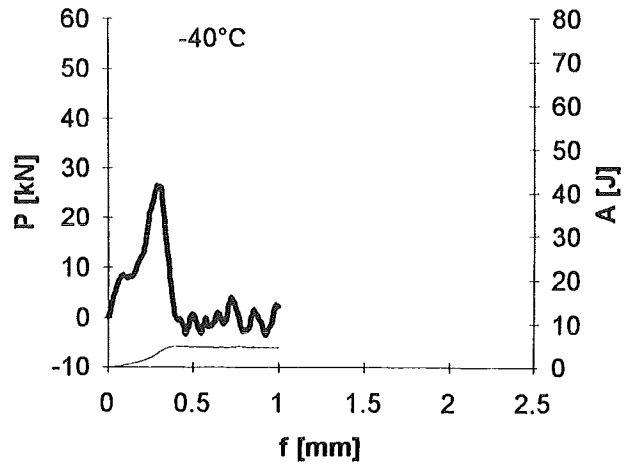
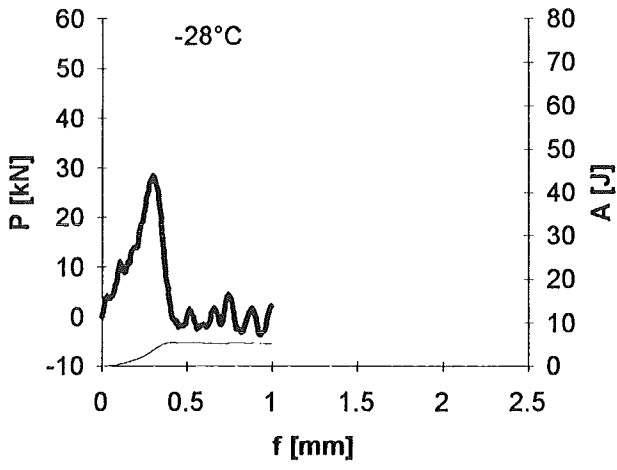




Appendix 3 (vervolg)

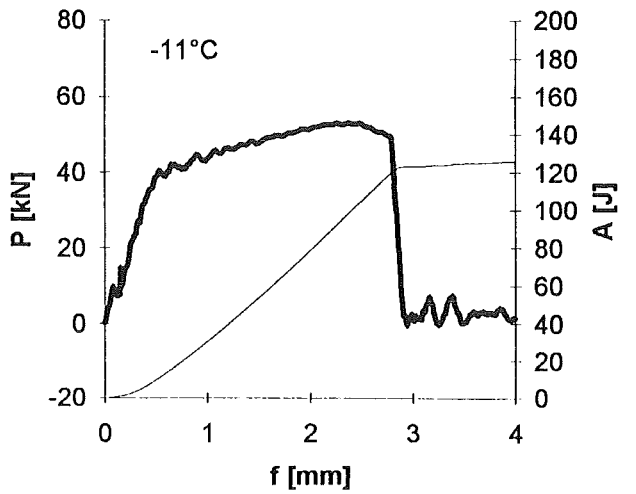
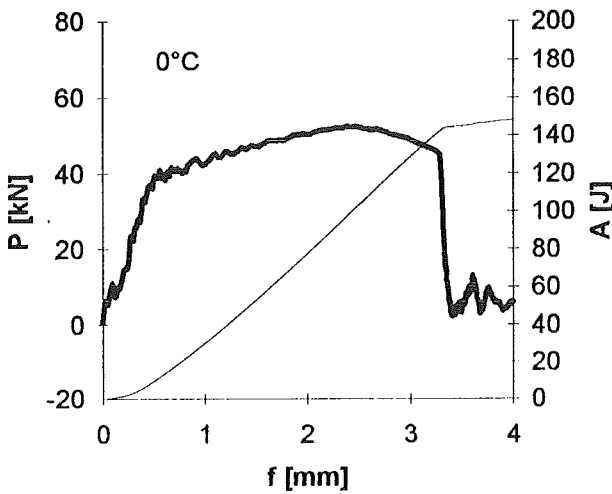
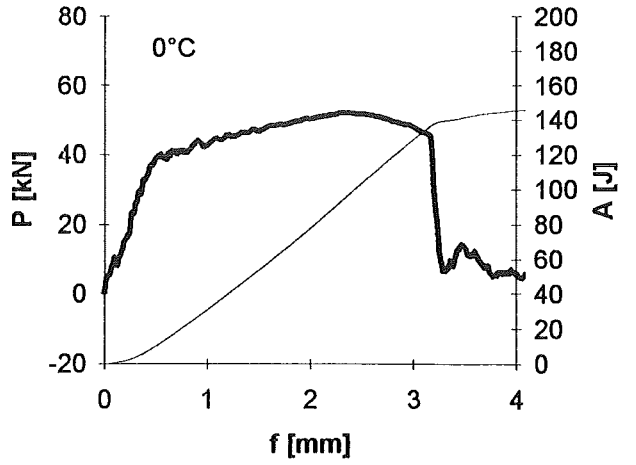
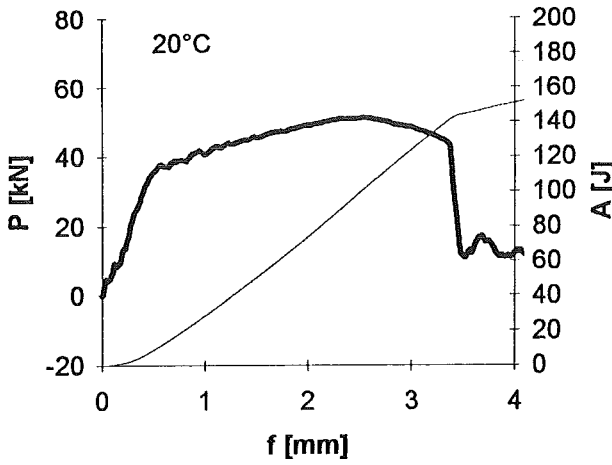
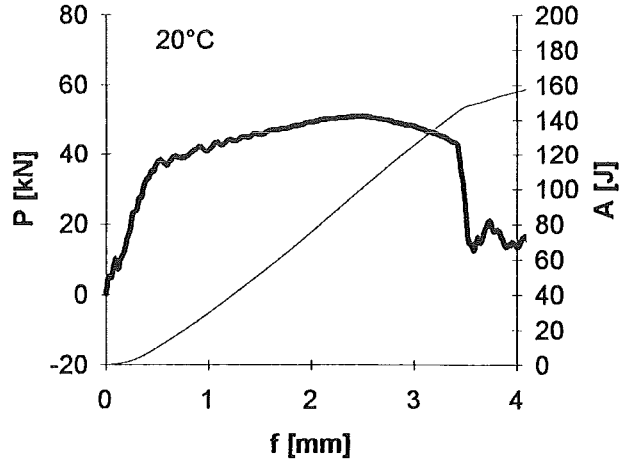
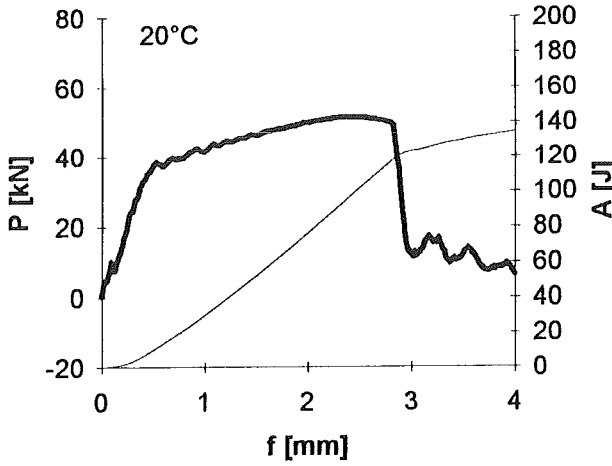
materiaal: 38MnSiV5-BY
proefstukken: V30mm
beproevingssnelheid: 3m/s.

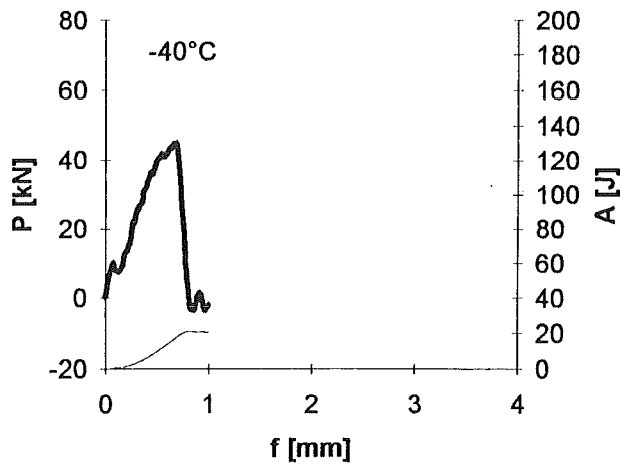
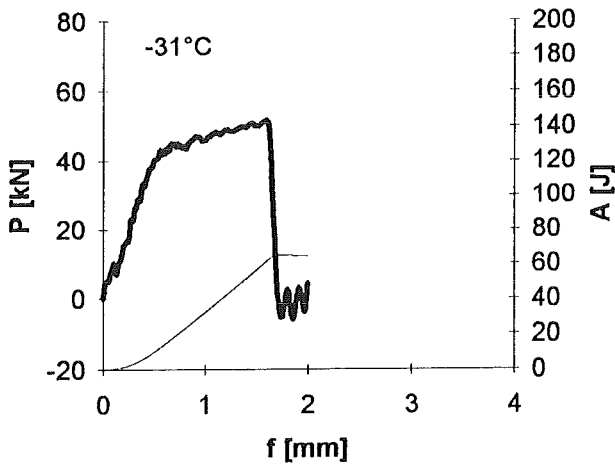
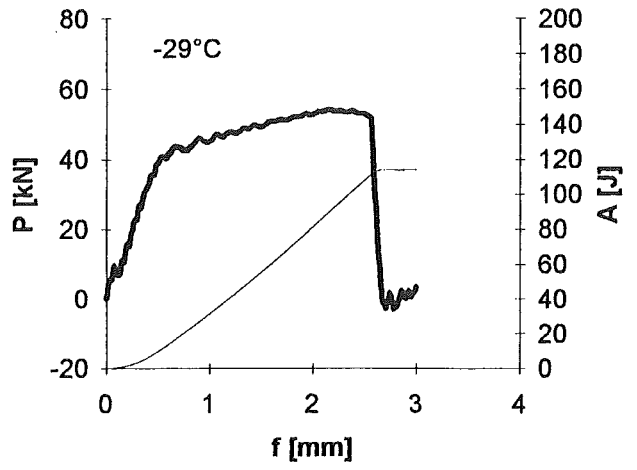
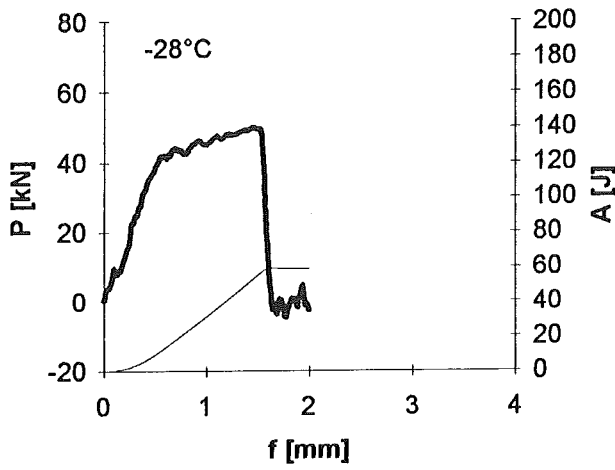
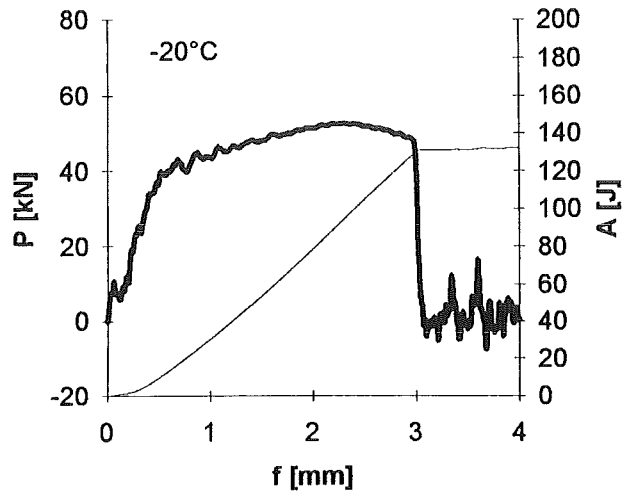
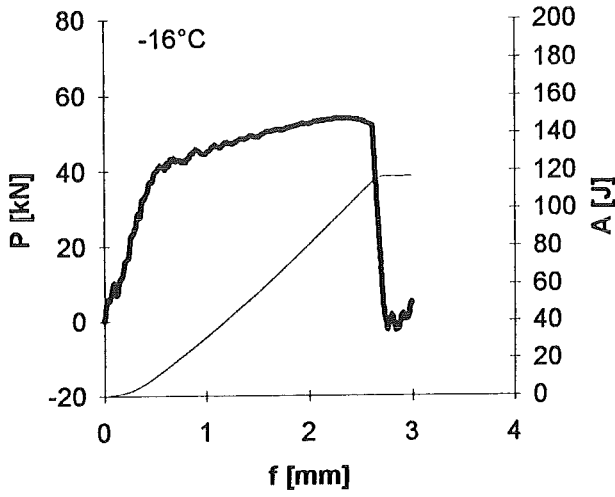


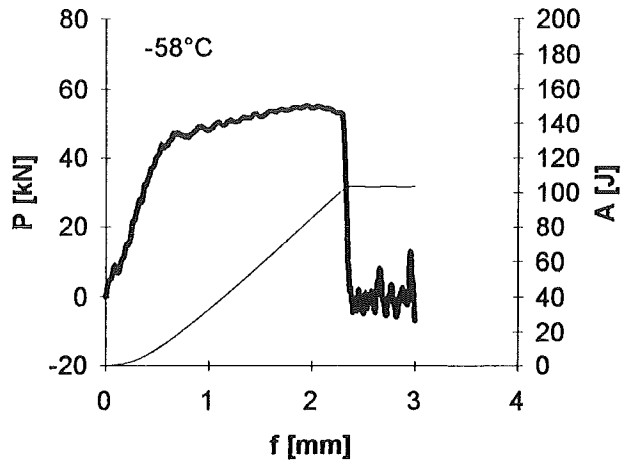
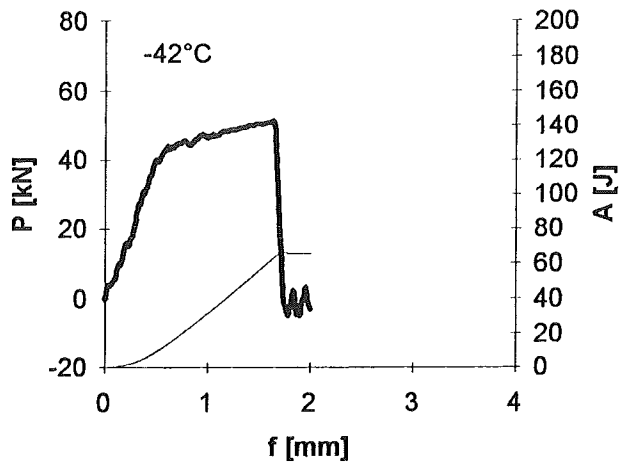


Appendix 3 (vervolg)

materiaal: 41CrS4-V
proefstukken: U30mm
beproevingssnelheid: 3m/s

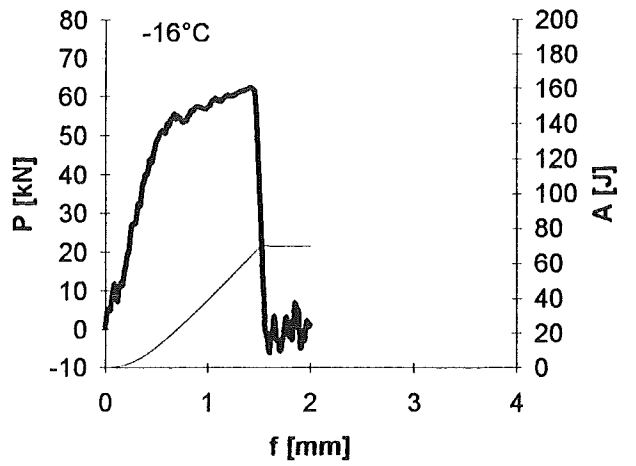
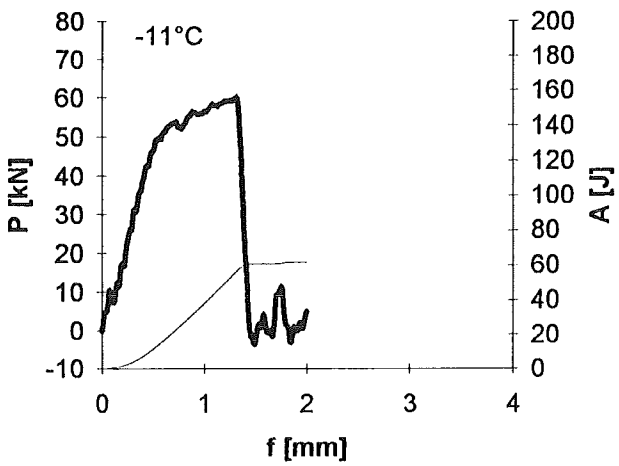
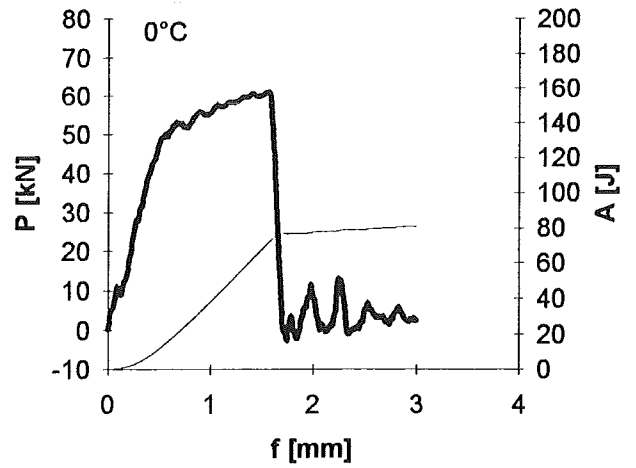
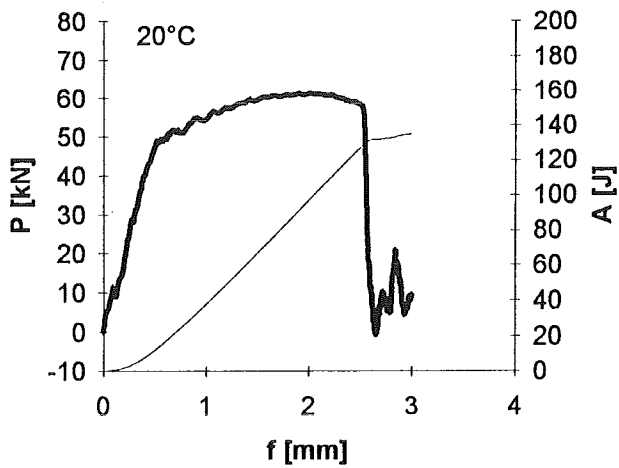
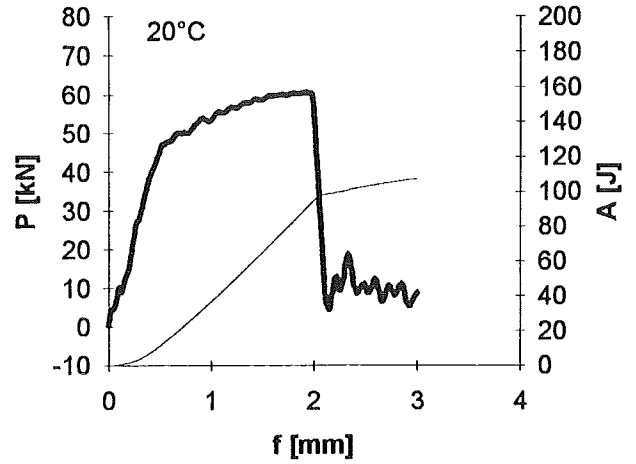
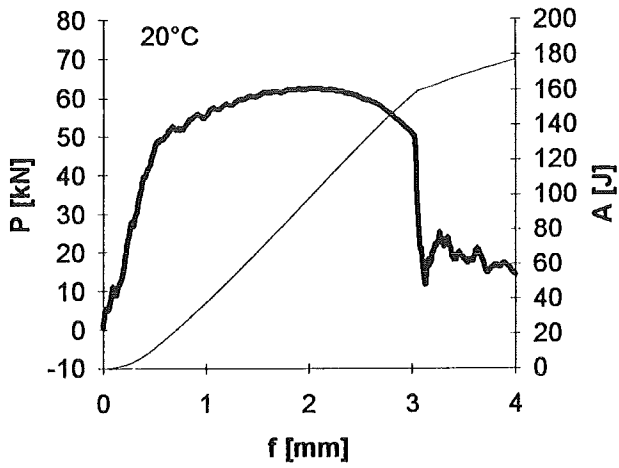


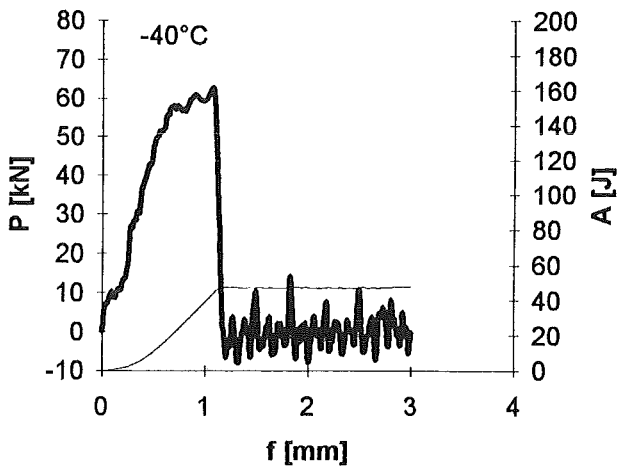
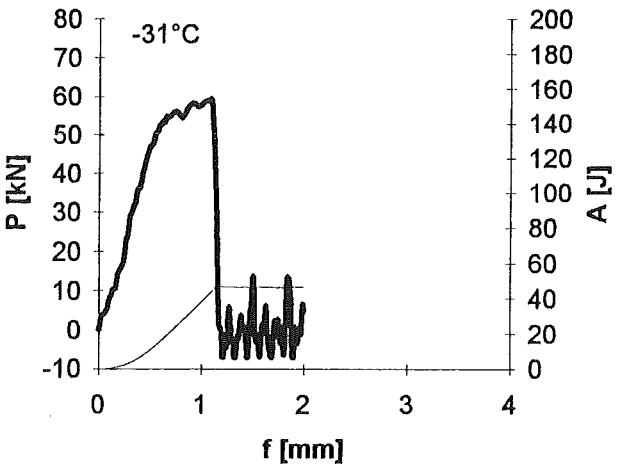
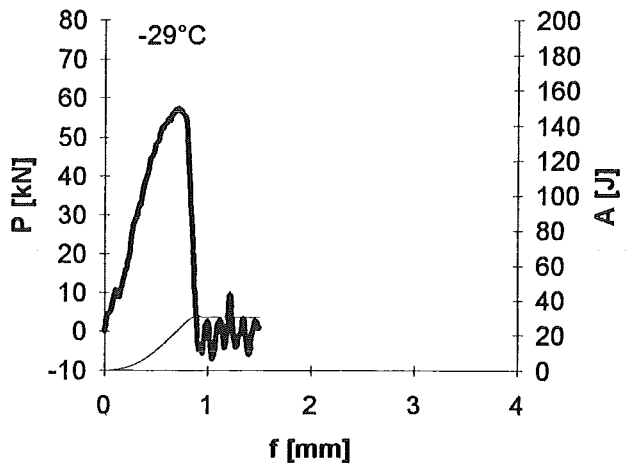
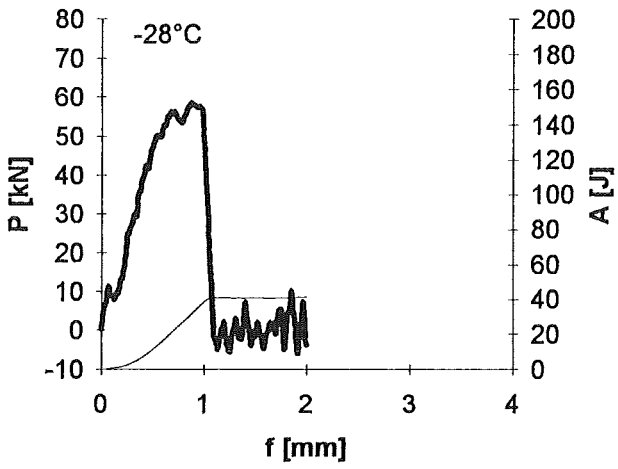
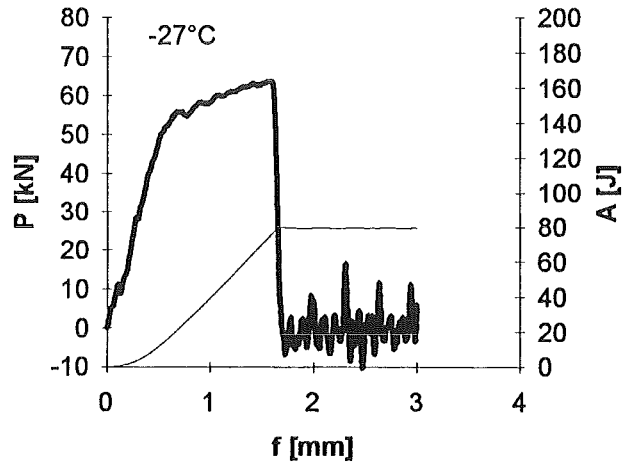
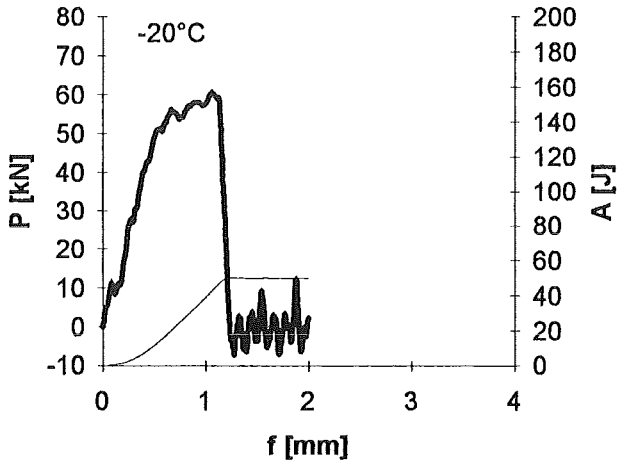


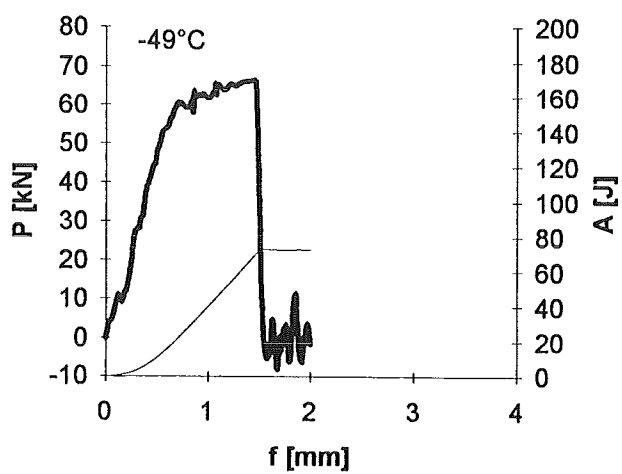
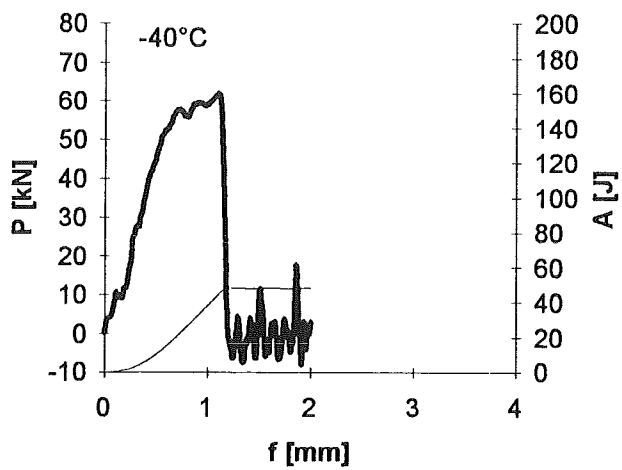


Appendix 3 (vervolg)

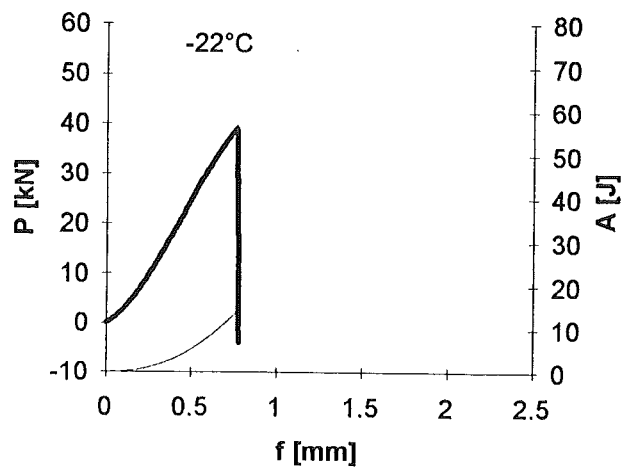
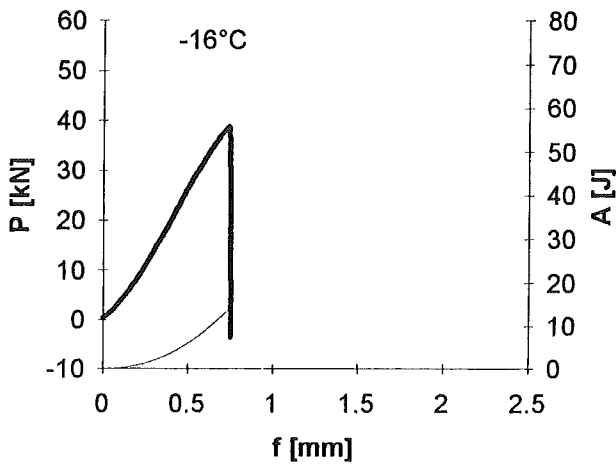
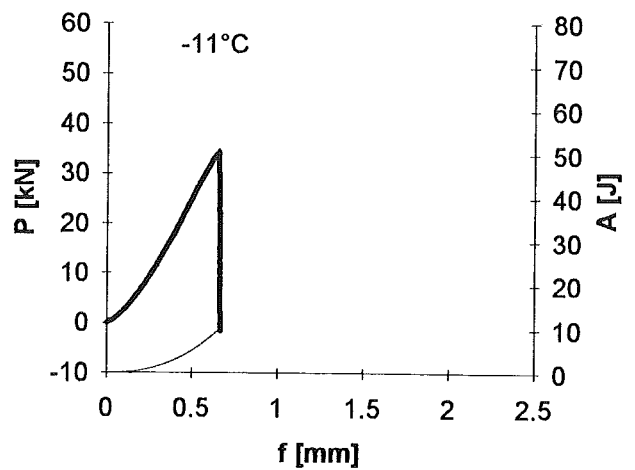
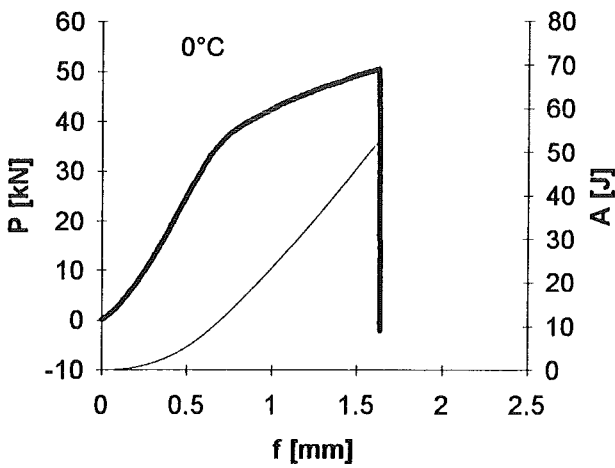
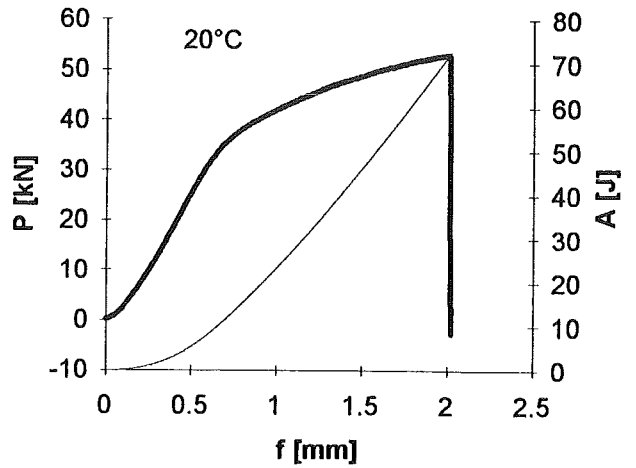
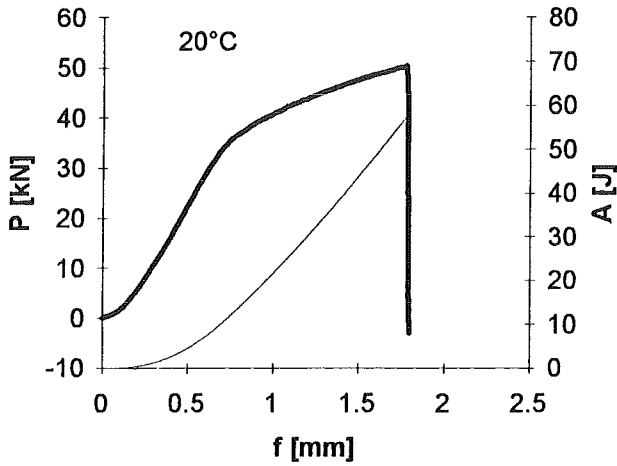
materiaal: 41CrS4-V
proefstukken: V30mm
beproevingssnelheid: 3m/s

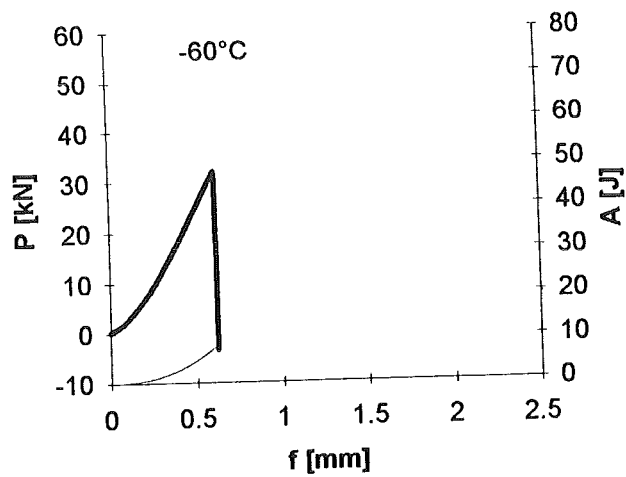
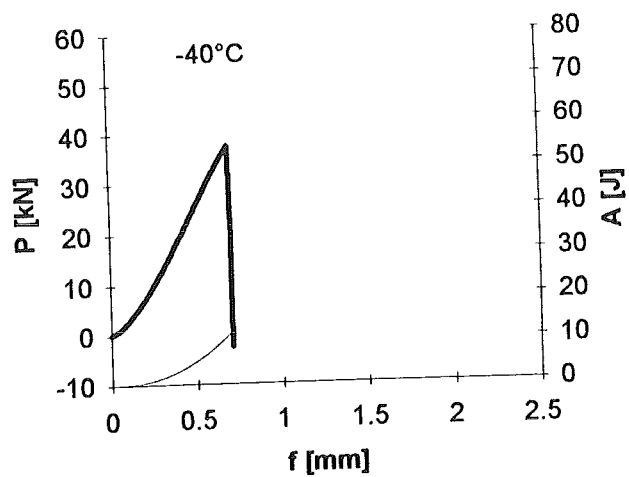






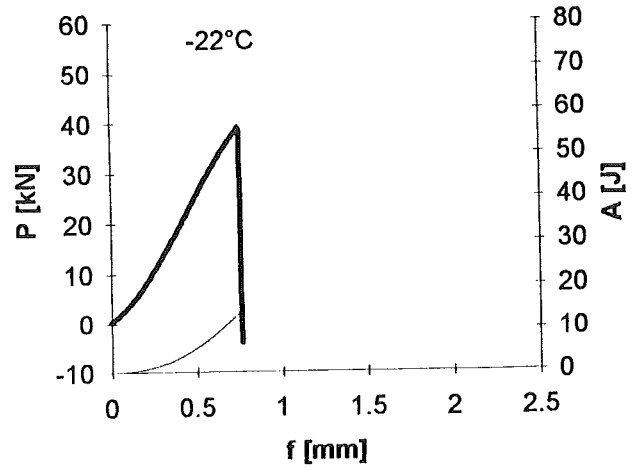
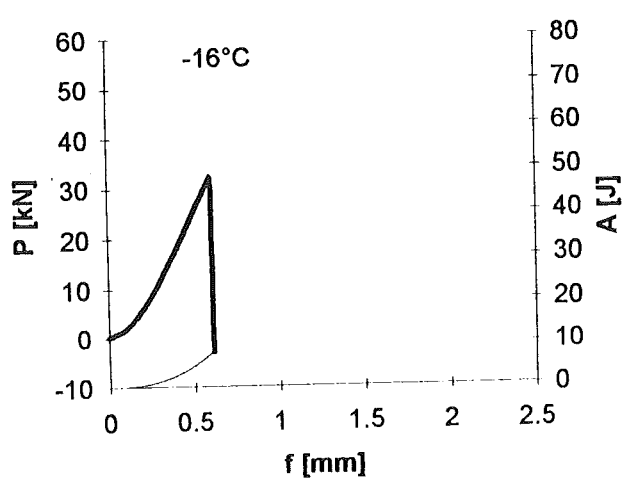
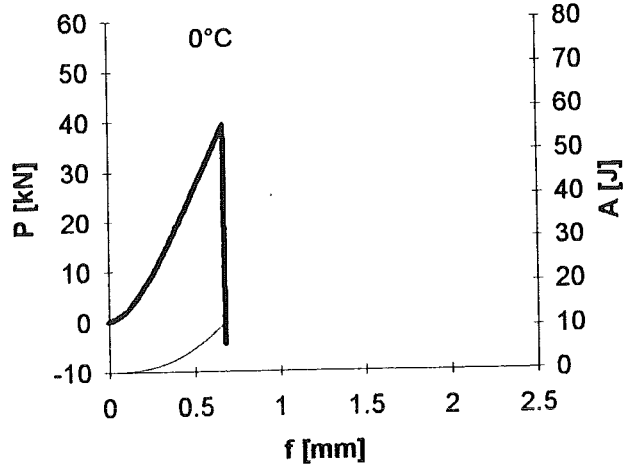
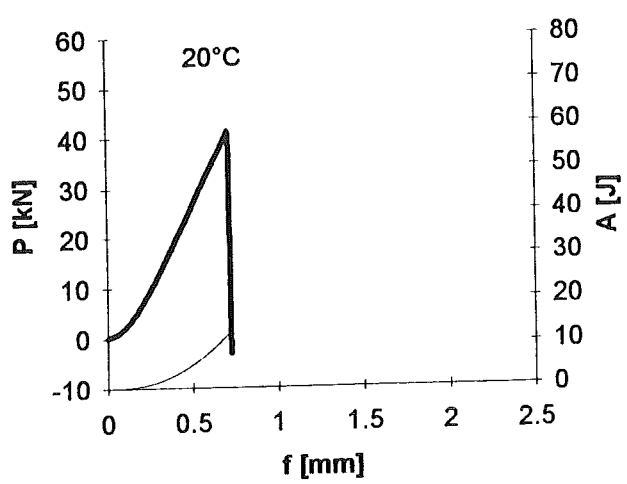
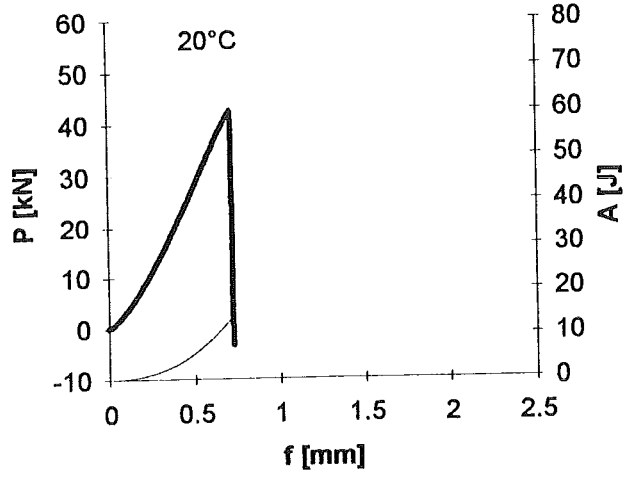
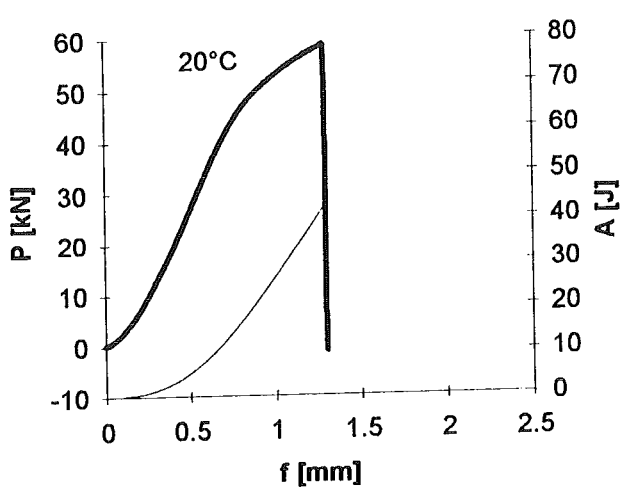
Appendix 4: Resultaten van de snelle driepuntsbuigproeven
kracht en energie als functie van de doorbuiging bij verschillende temperaturen
materiaal: 38MnSiVS5-BY
proefstukken: U30mm
beproevingssnelheid: 0.01m/s

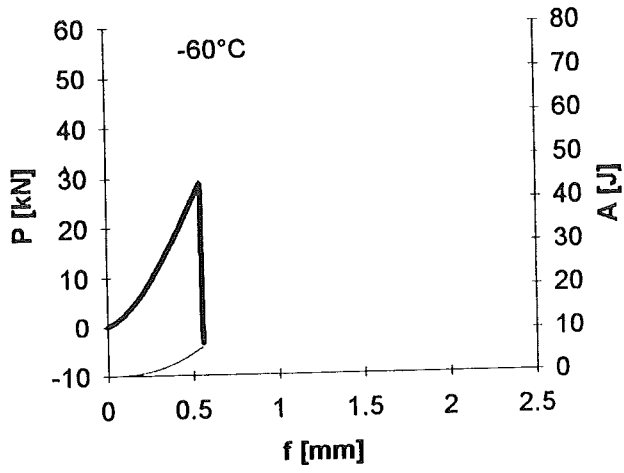
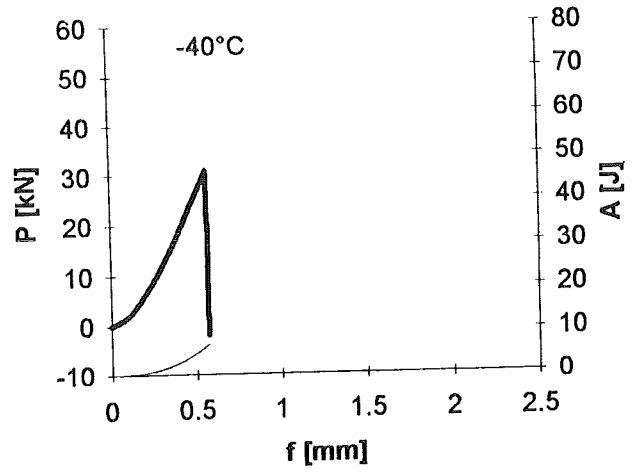
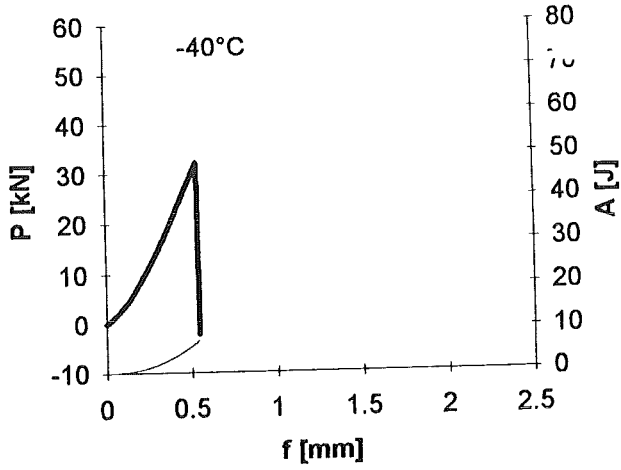




Appendix 4 (vervolg)

materiaal: 38MnSiVS5-BY
proefstukken: V30mm
beproevingssnelheid: 0.01m/s



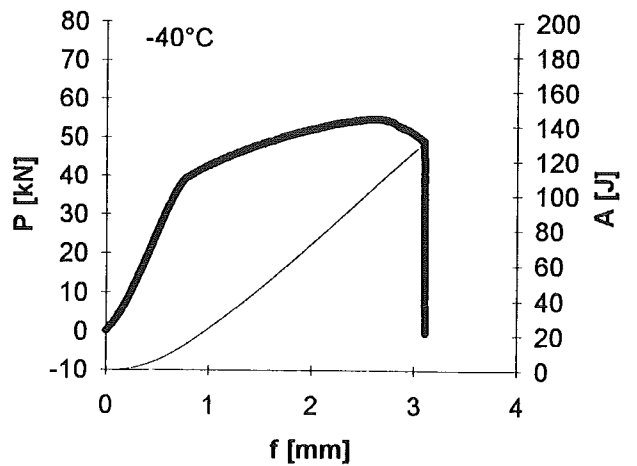
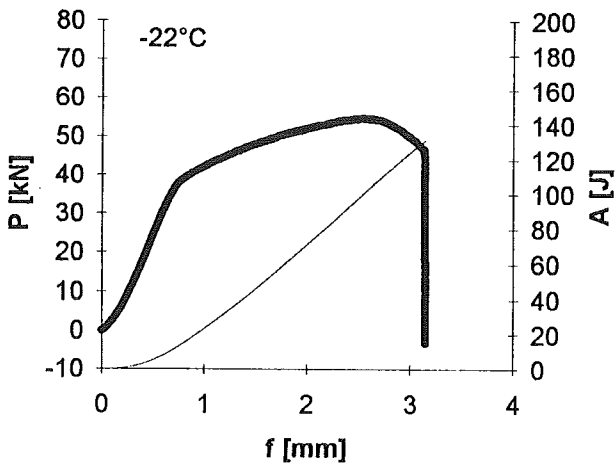
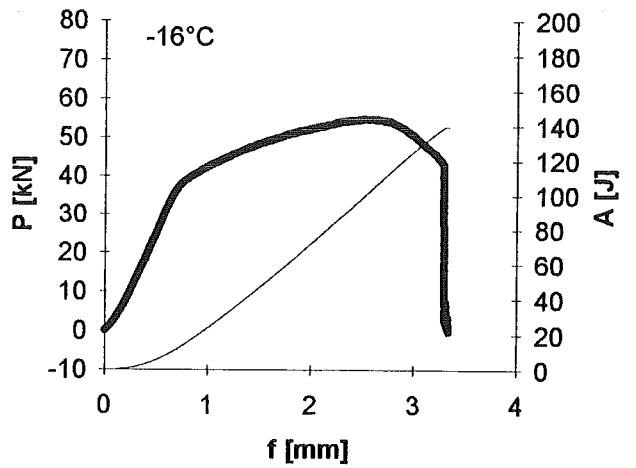
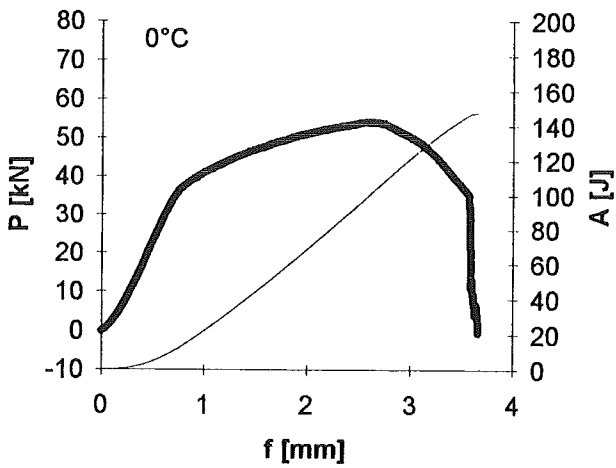
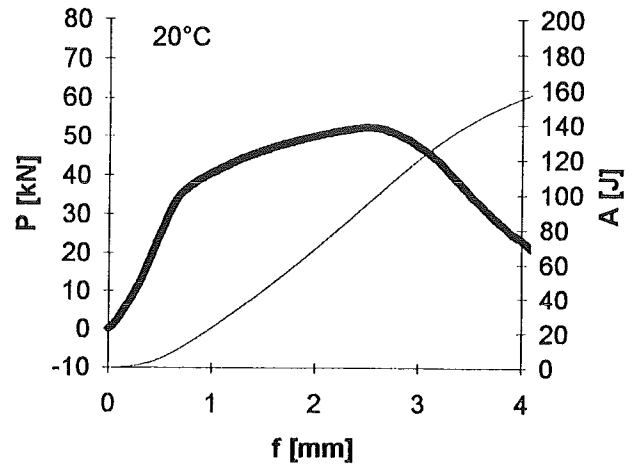
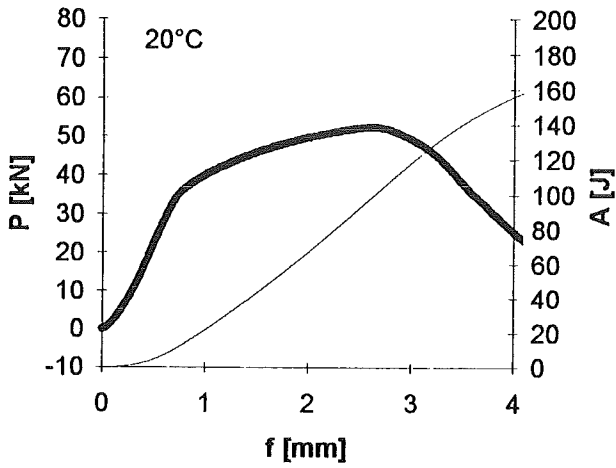


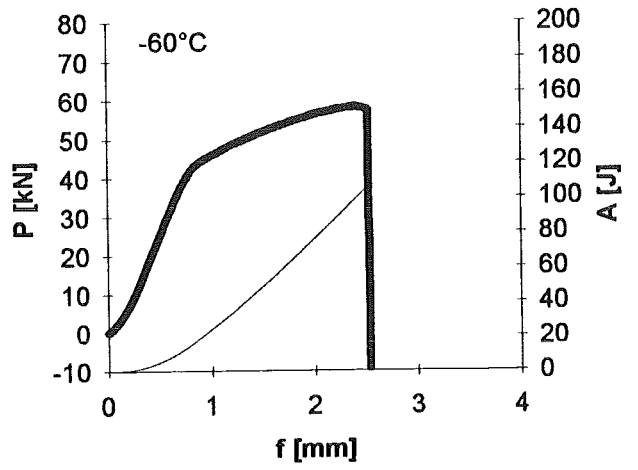
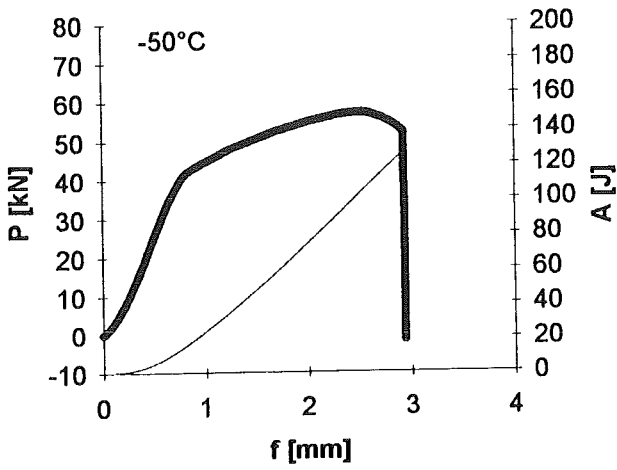
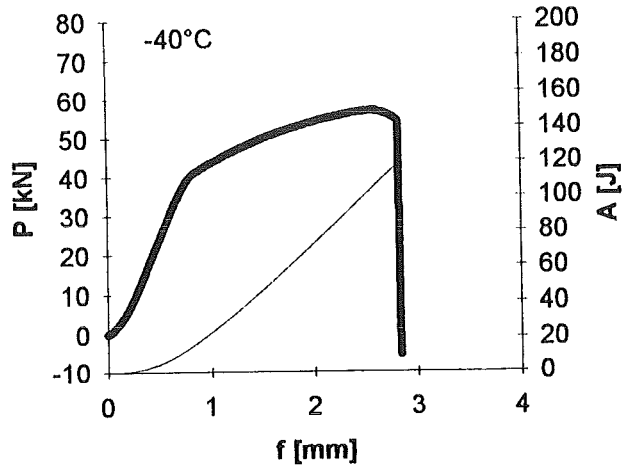
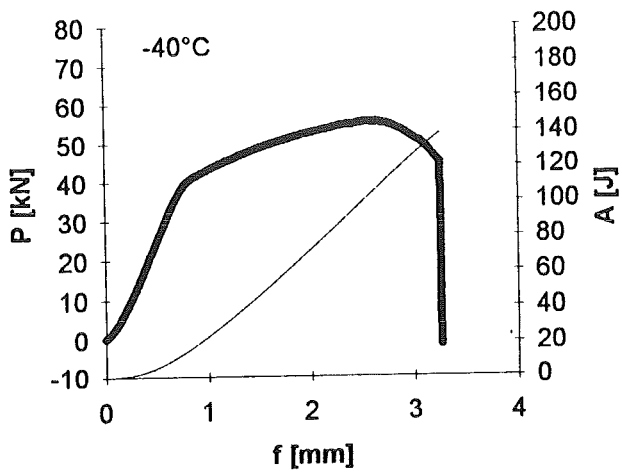
Appendix 4 (vervolg)

materiaal: 41CrS4-V

proefstukken: U30mm

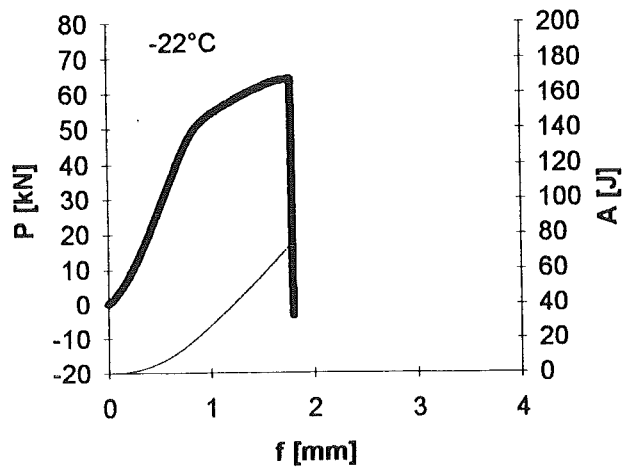
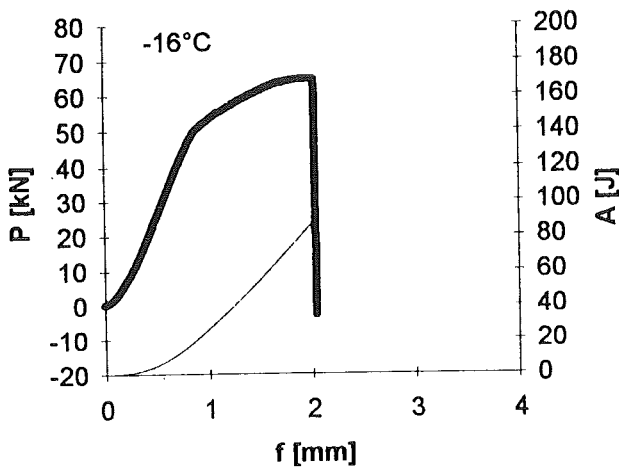
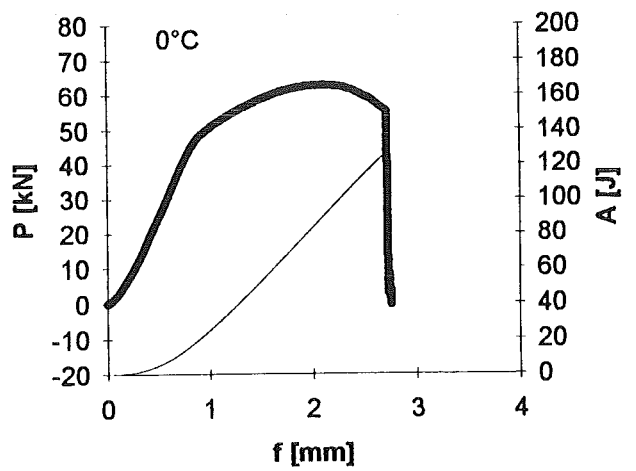
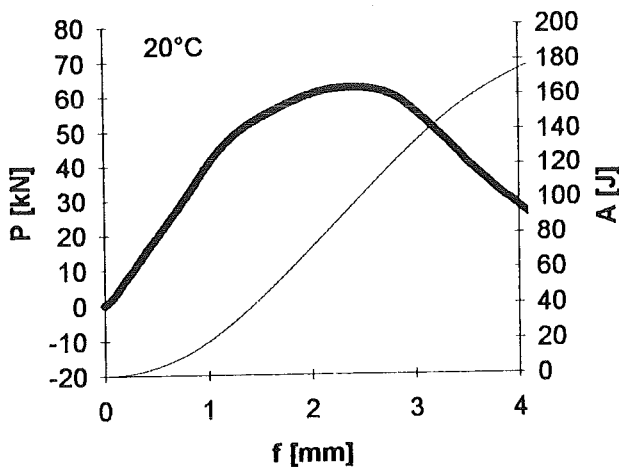
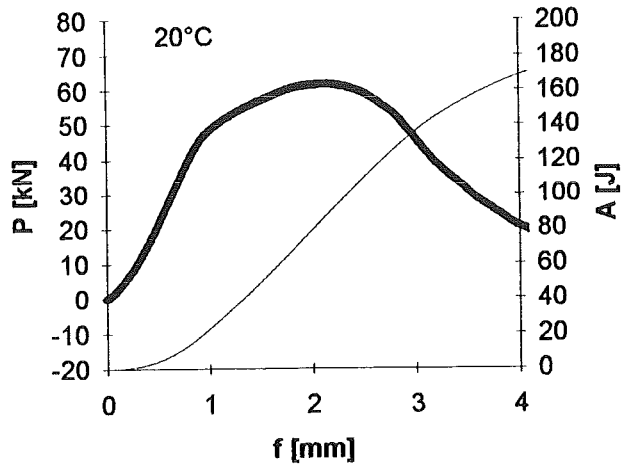
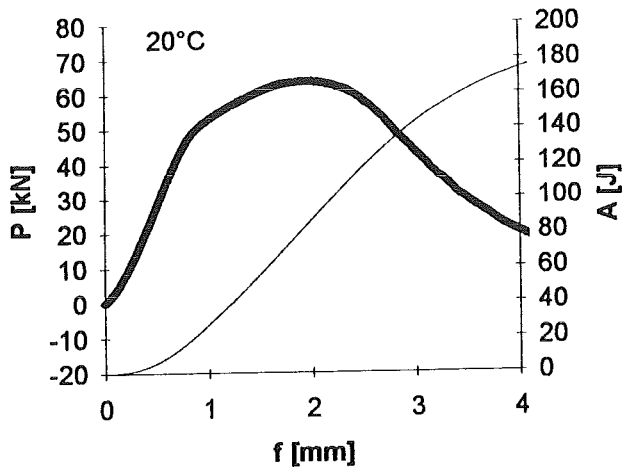
beproevingssnelheid: 0.01m/s

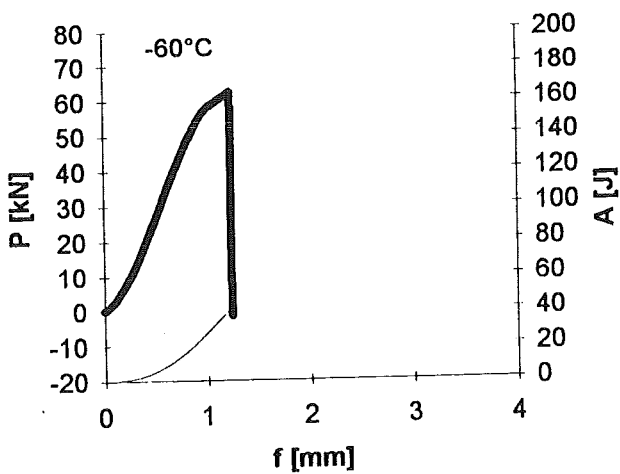
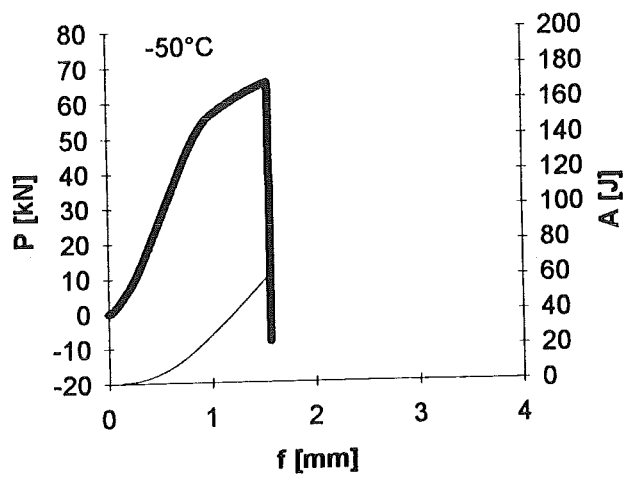
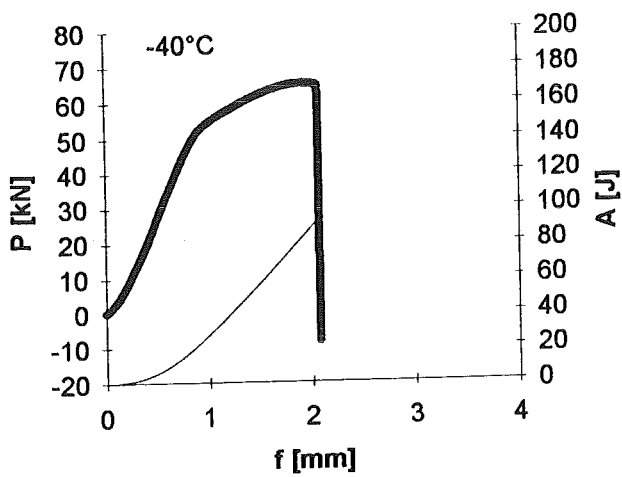
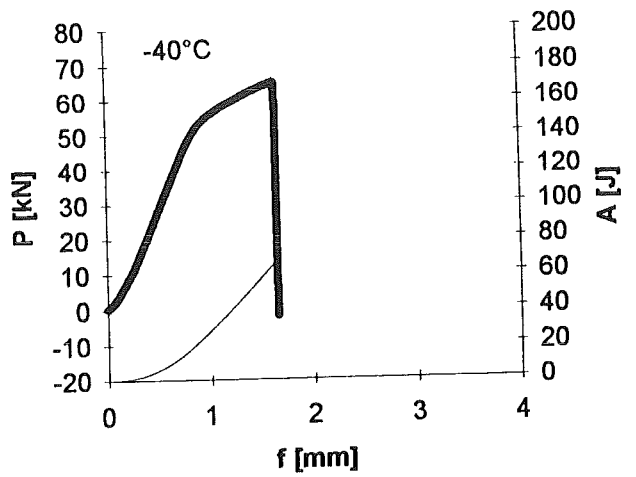
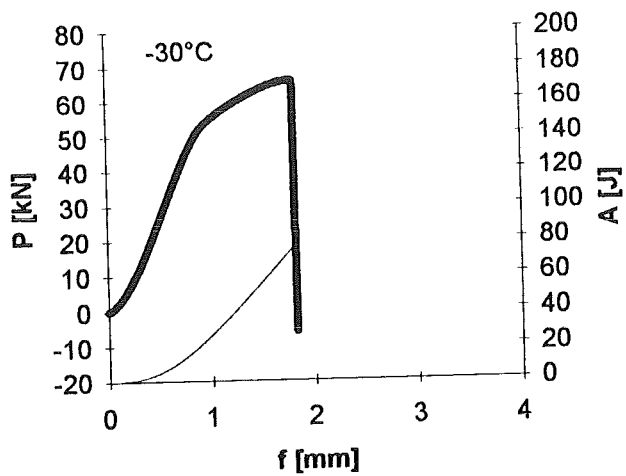




Appendix 4 (vervolg)

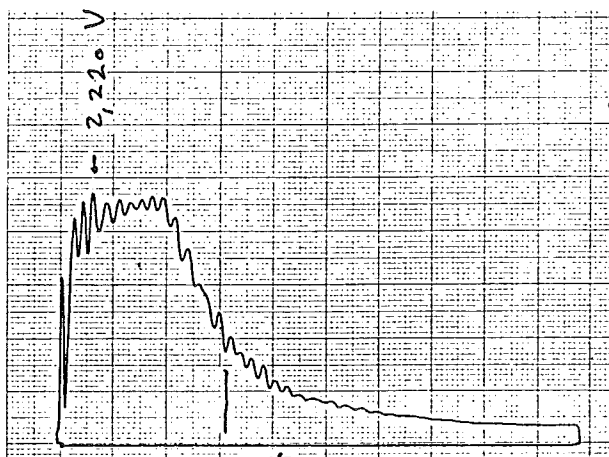
materiaal: 41CrS4-V
proefstukken: V30mm
beproevingssnelheid: 0.01m/s



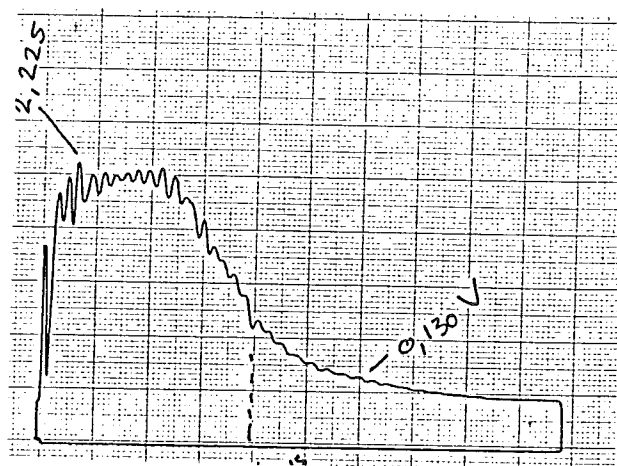


APPENDIX 5: KRACHT-TIJD-DIAGRAMMEN VAN DE GEÏNSTRUMENTEERDE KERFSLAGPROEVEN

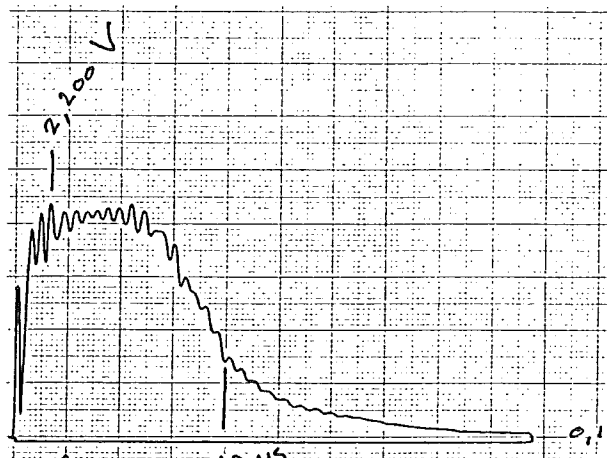
Materiaal: 33MnCrB5.2-V
Proefstuk: U_{10mm}
Horizontaal: schaaldeel 200 μs
Verticaal: schaaldeel 8 kN



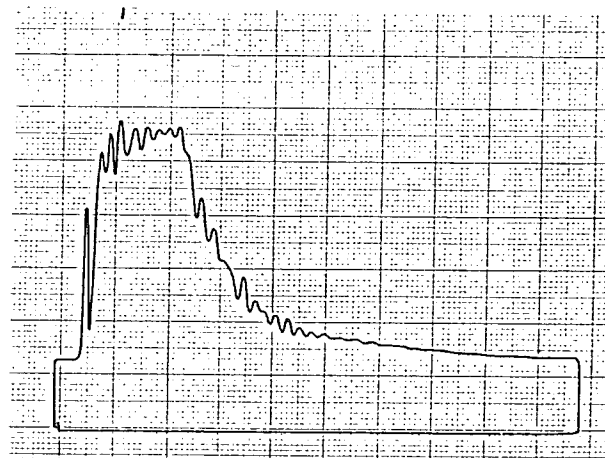
T=20°C



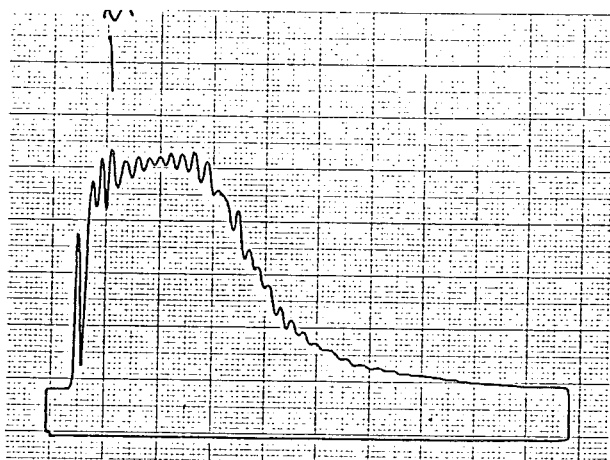
T=20°C



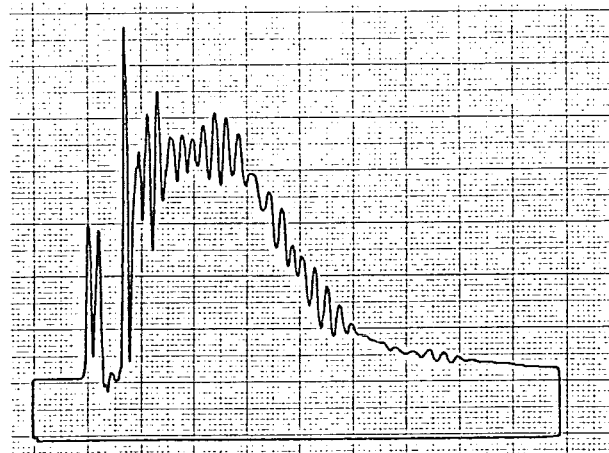
T=20°C



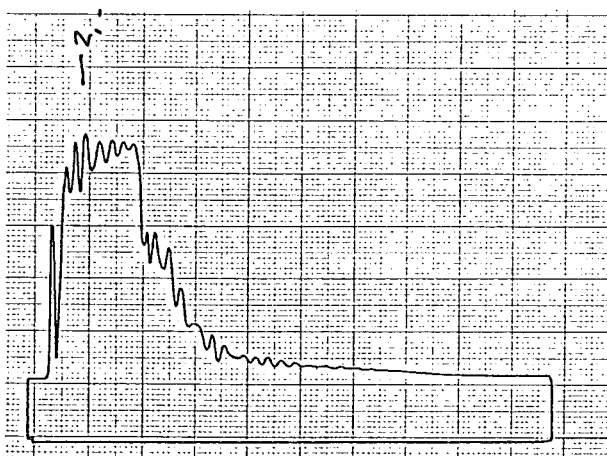
T=0°C



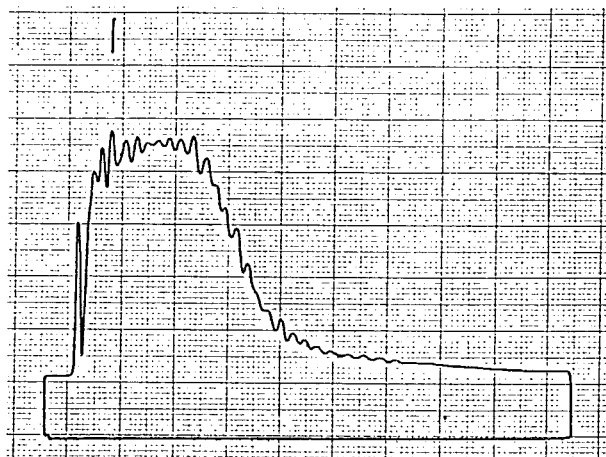
$T=0^{\circ}\text{C}$



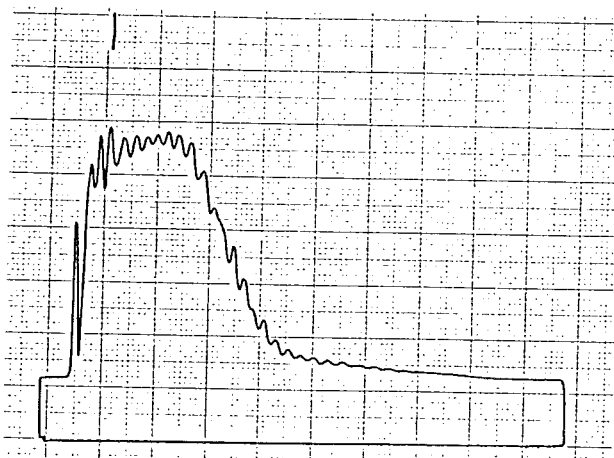
$T=0^{\circ}\text{C}$



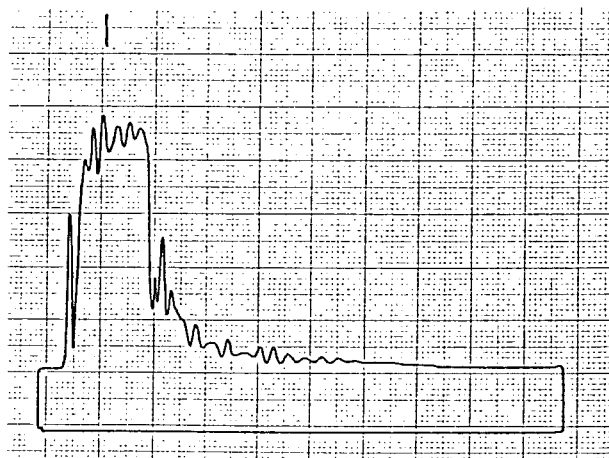
$T=-20^{\circ}\text{C}$



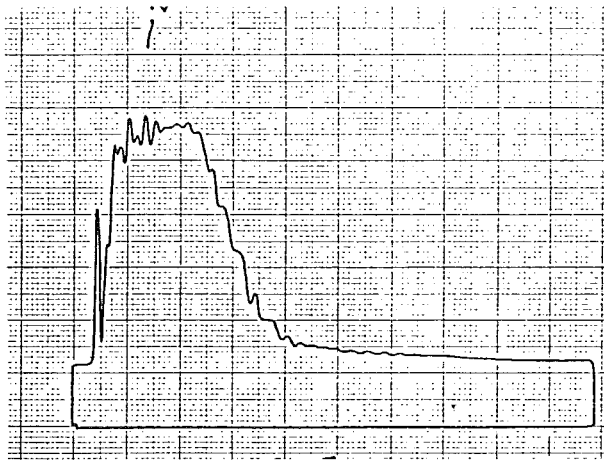
$T=-20^{\circ}\text{C}$



$T=-20^{\circ}\text{C}$



$T=-40^{\circ}\text{C}$

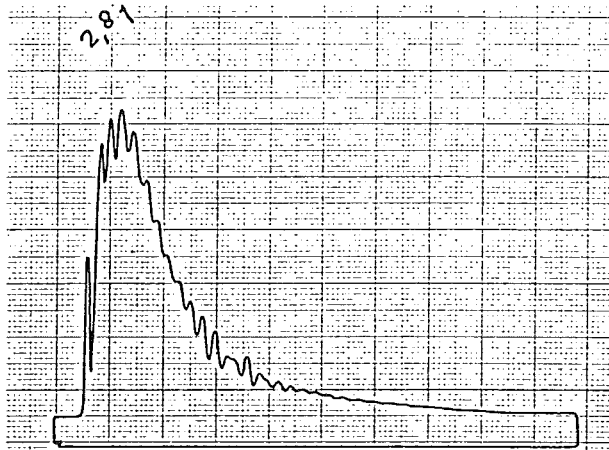


$T = -40^{\circ}\text{C}$

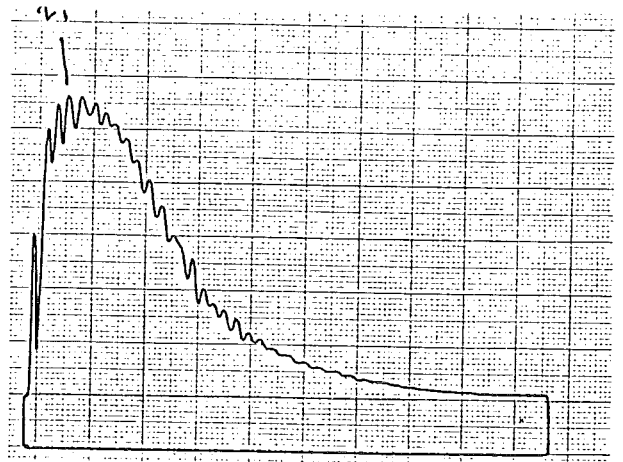


$T = -40^{\circ}\text{C}$

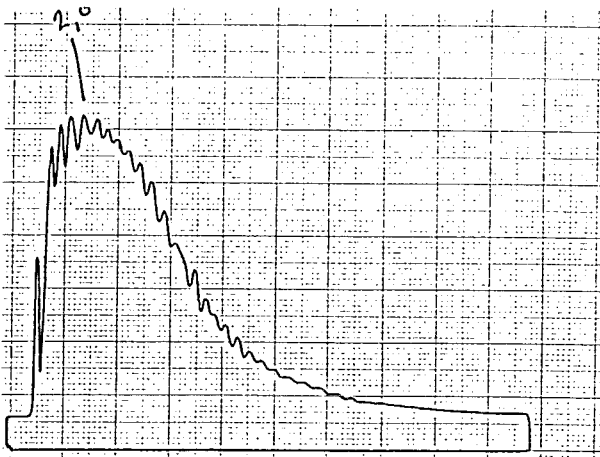
Materiaal: 33MnCrB5.2-V
Proefstuk: V_{10mm}
Horizontaal: schaaldeel 200 μ s
Verticaal: schaaldeel 8 kN



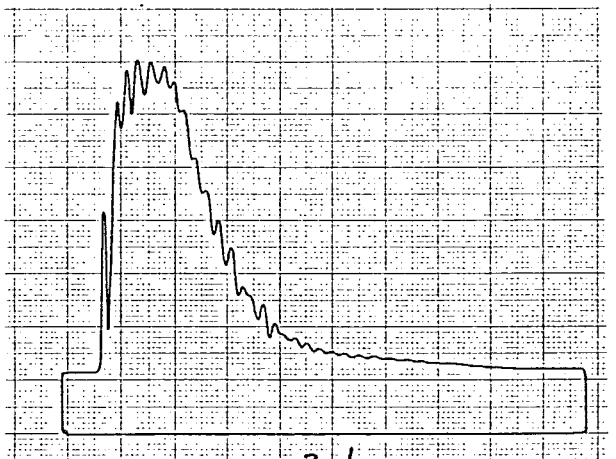
T=20°C



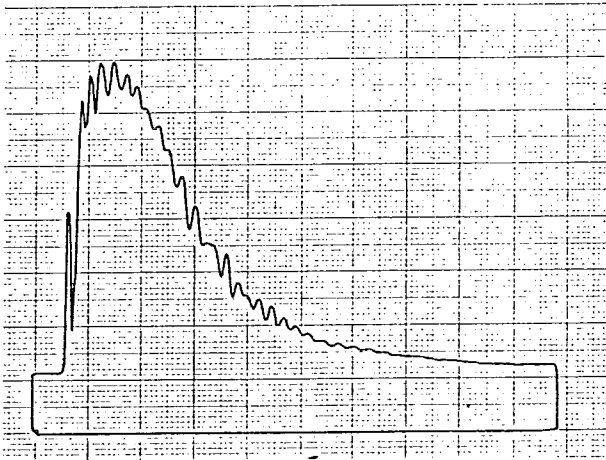
T=20°C



T=20°C



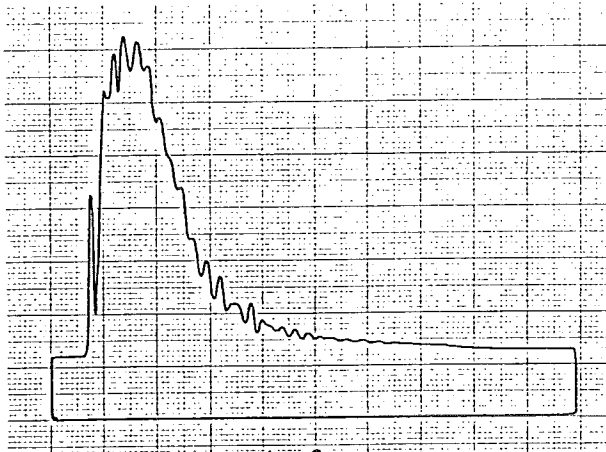
T=0°C



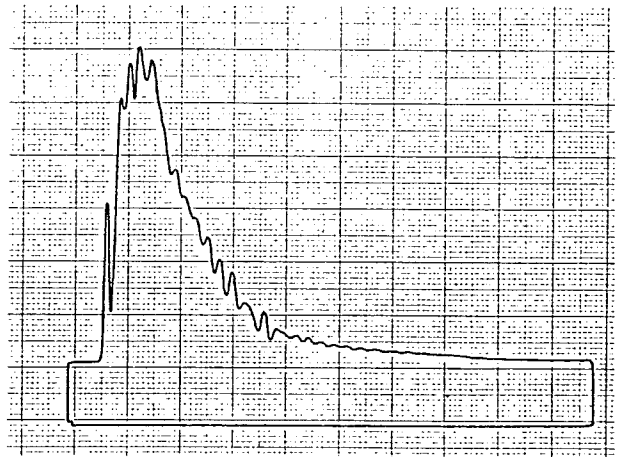
$T=0^{\circ}\text{C}$



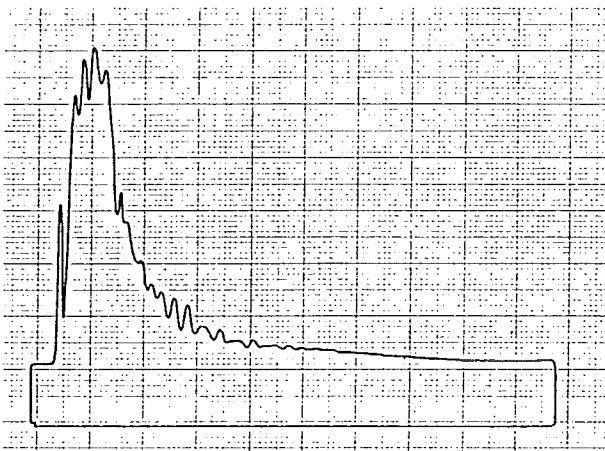
$T=0^{\circ}\text{C}$



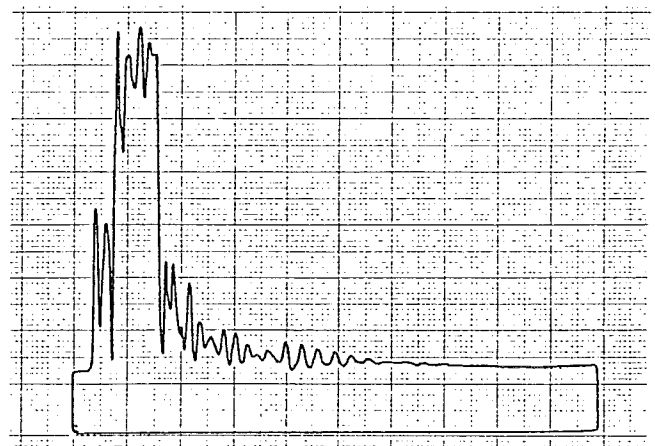
$T=-20^{\circ}\text{C}$



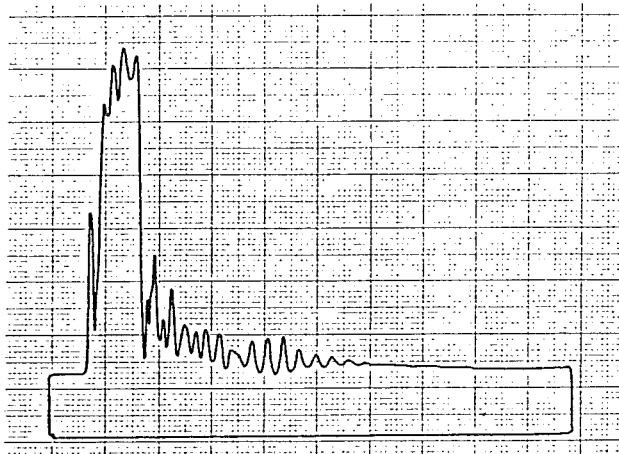
$T=-20^{\circ}\text{C}$



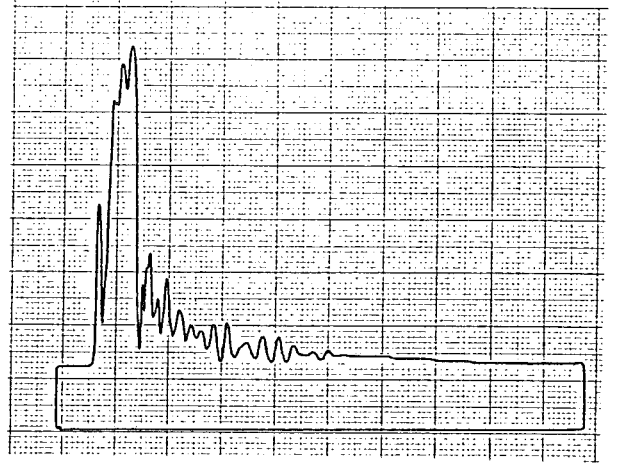
$T=-20^{\circ}\text{C}$



$T=-40^{\circ}\text{C}$

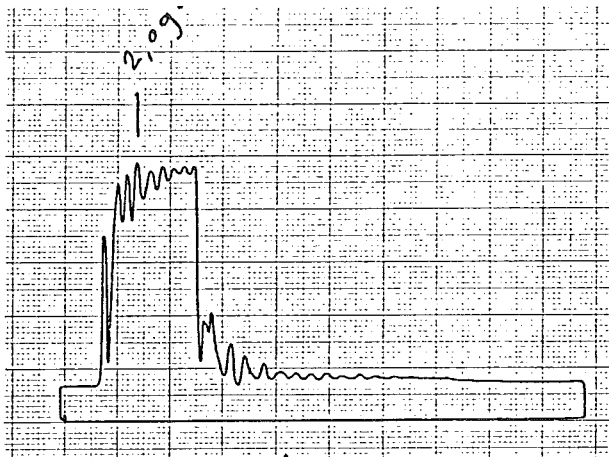


T=-40°C



T=-40°C

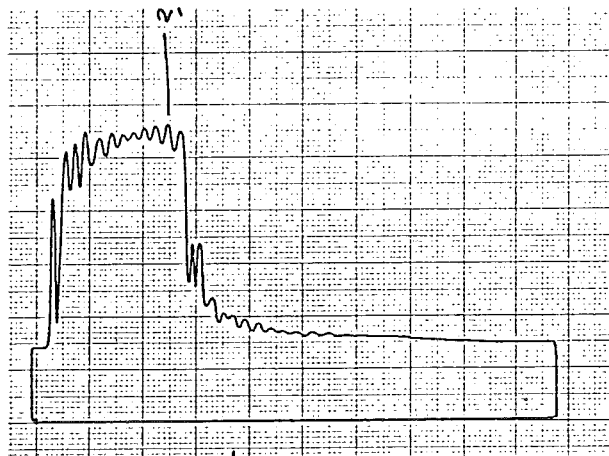
Materiaal: 33MnCrB5.2-VS
Proefstuk: $U_{10\text{mm}}$
Horizontaal: schaaldeel $200 \mu\text{s}$
Verticaal: schaaldeel 8 kN



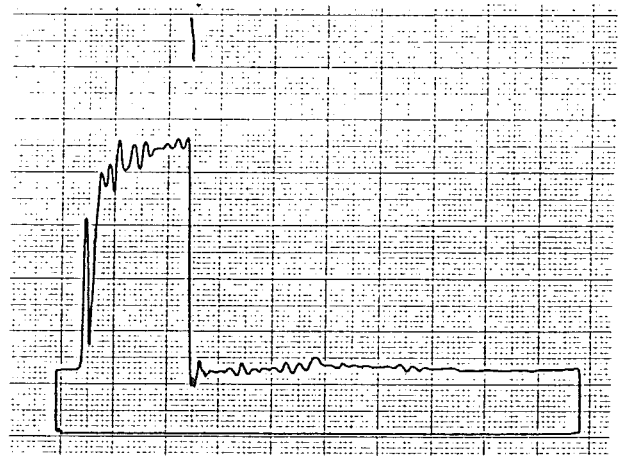
$T=20^\circ\text{C}$



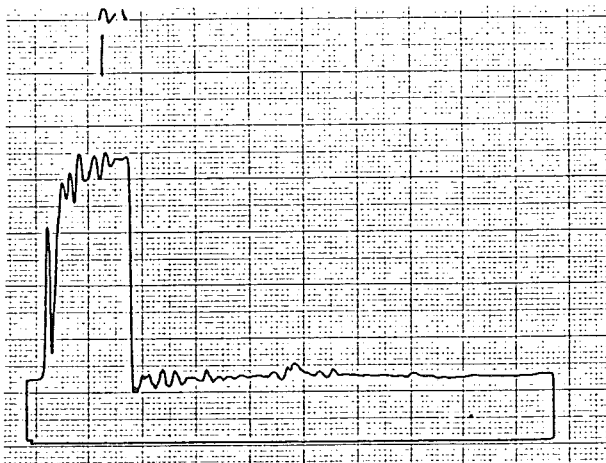
$T=20^\circ\text{C}$



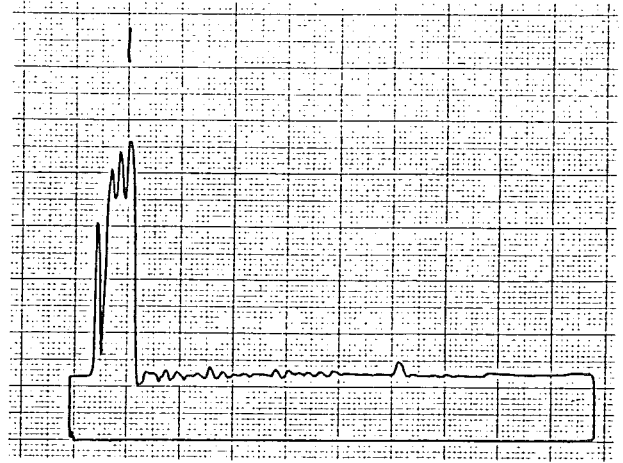
$T=20^\circ\text{C}$



$T=-20^\circ\text{C}$



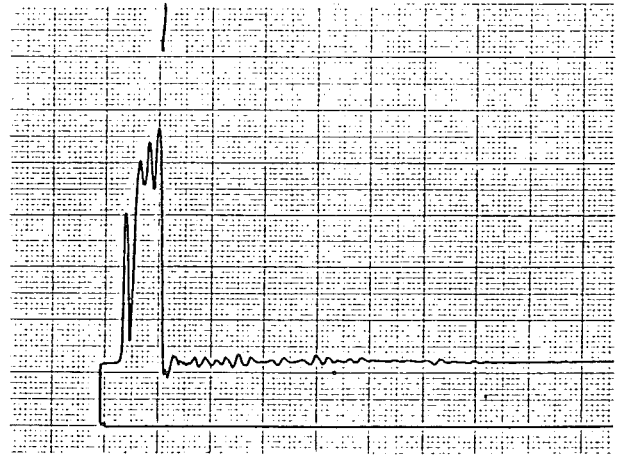
$T = -20^{\circ}\text{C}$



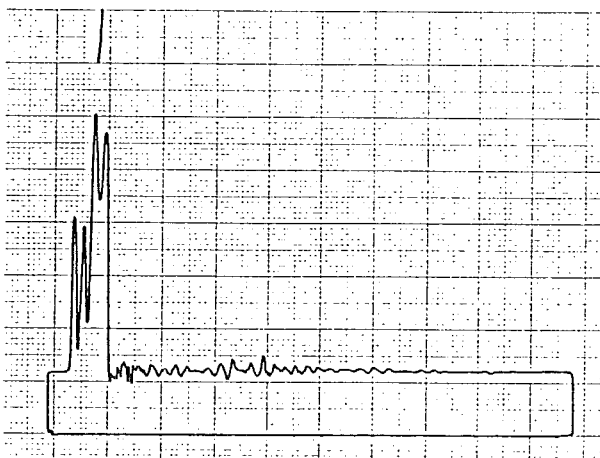
$T = -20^{\circ}\text{C}$



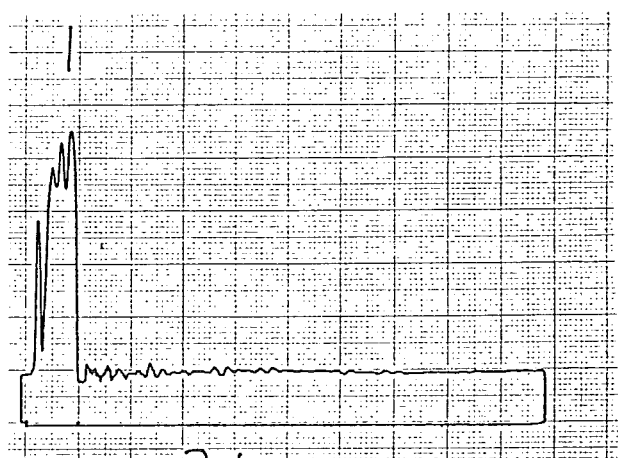
$T = -40^{\circ}\text{C}$



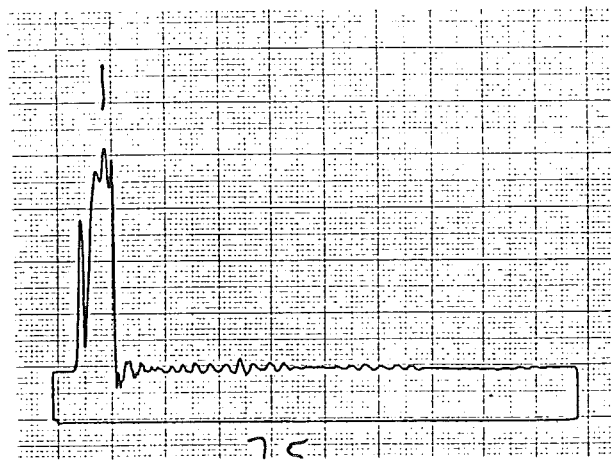
$T = -40^{\circ}\text{C}$



$T = -40^{\circ}\text{C}$



$T = -60^{\circ}\text{C}$

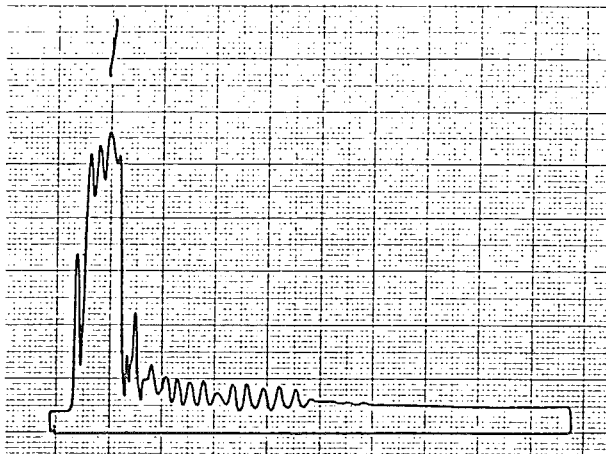


$T = -60^{\circ}\text{C}$



$T = -60^{\circ}\text{C}$

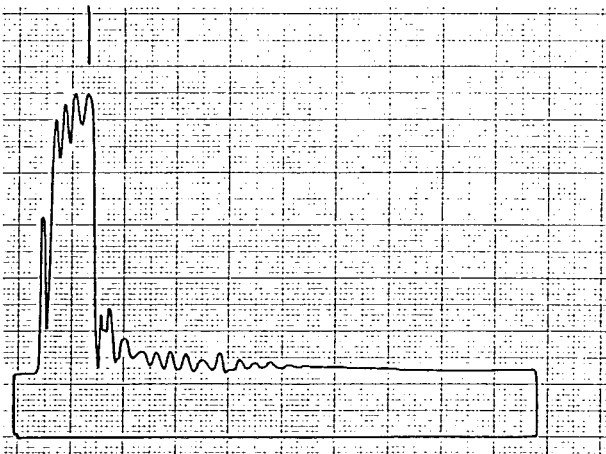
Materiaal: 33MnCrB5.2-VS
Proefstuk: $V_{10\text{mm}}$
Horizontaal: schaaldeel 200 μs
Verticaal: schaaldeel 8 kN



T=20°C



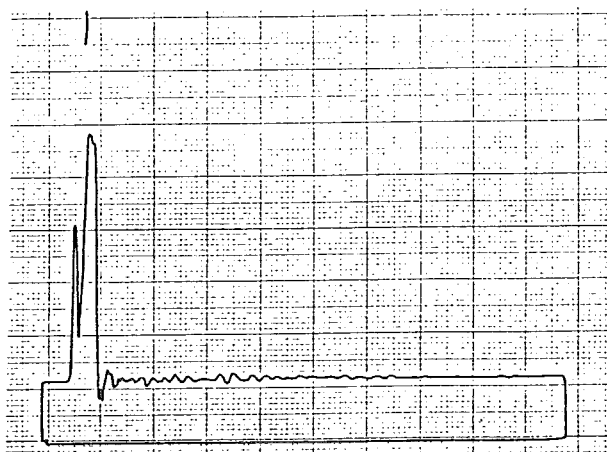
T=20°C



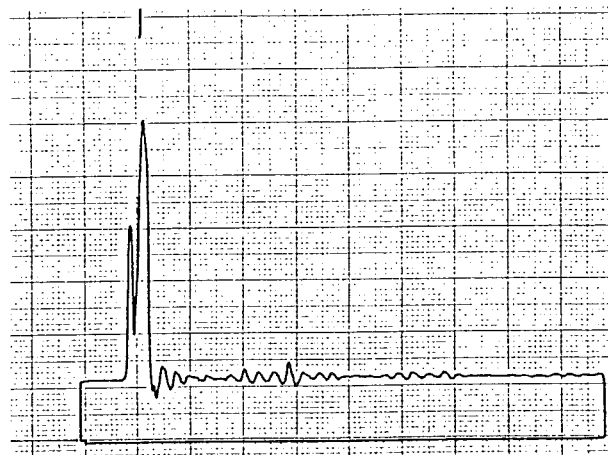
T=20°C



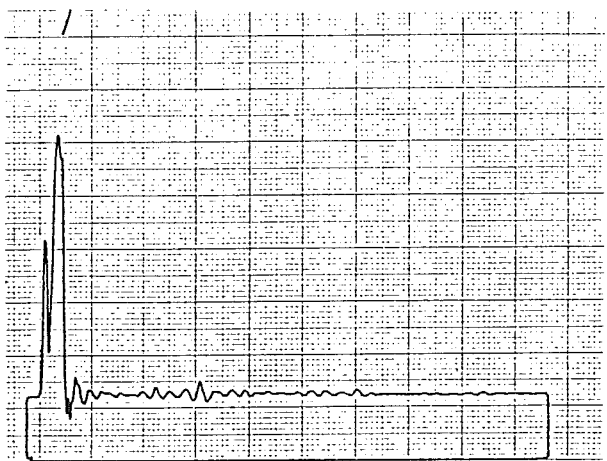
T=-20°C



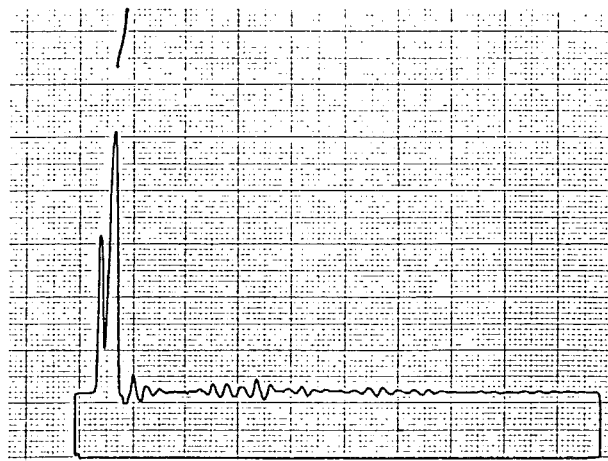
$T = -20^{\circ}\text{C}$



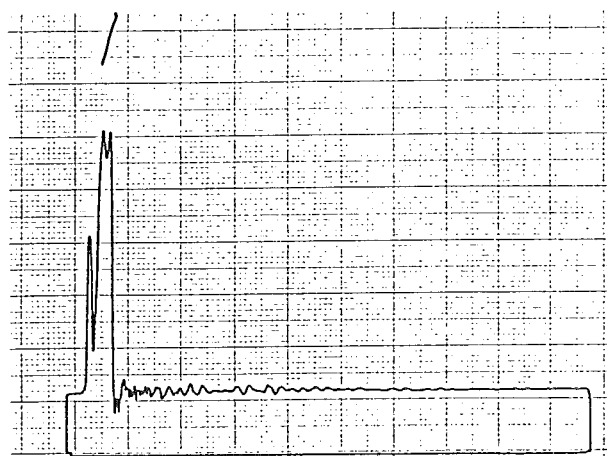
$T = -20^{\circ}\text{C}$



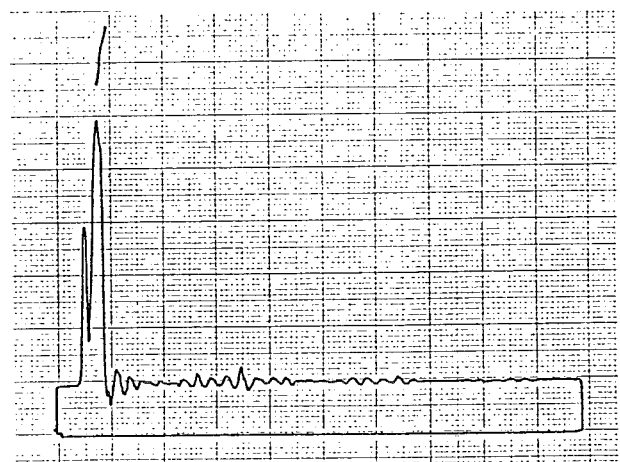
$T = -40^{\circ}\text{C}$



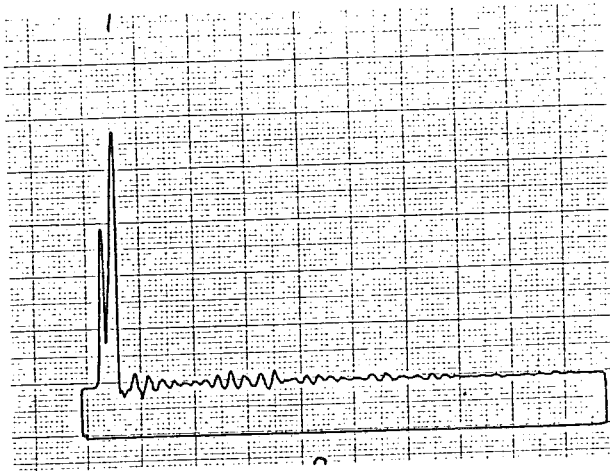
$T = -40^{\circ}\text{C}$



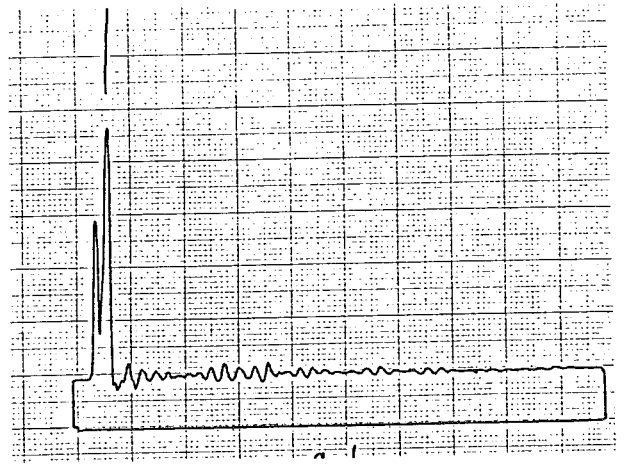
$T = -40^{\circ}\text{C}$



$T = -60^{\circ}\text{C}$

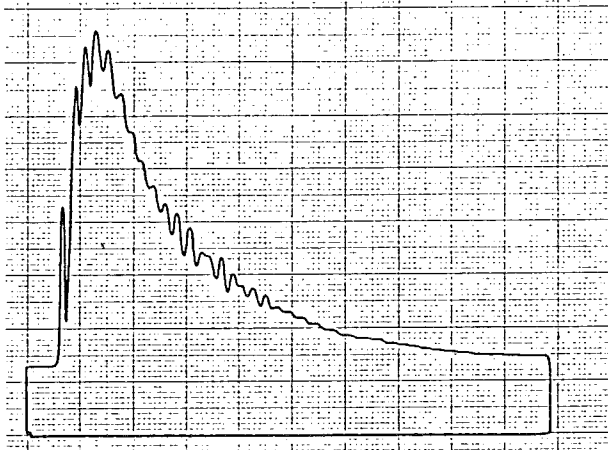


$T = -60^{\circ}\text{C}$

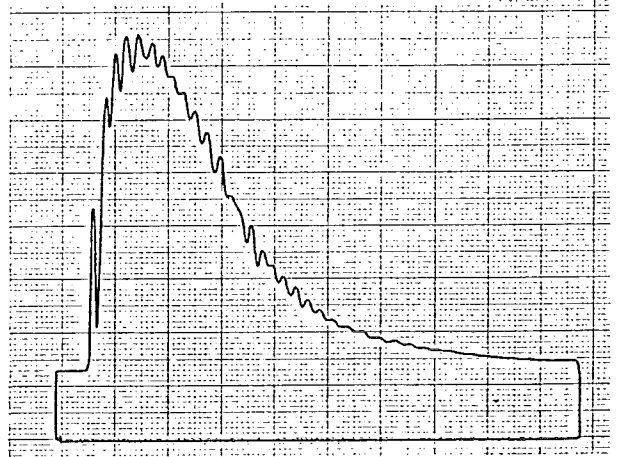


$T = -60^{\circ}\text{C}$

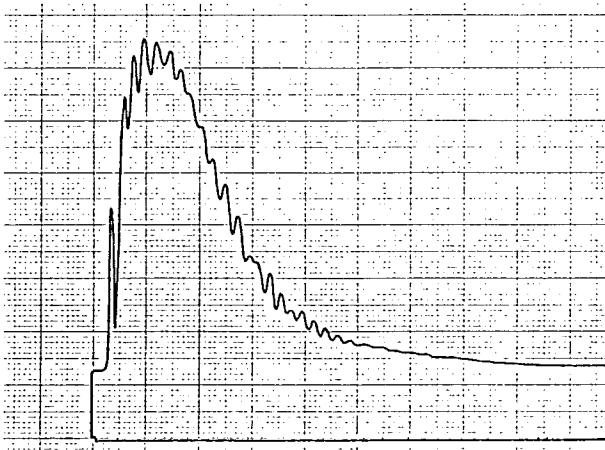
Materiaal: 41CrS4-V^D
Proefstuk: V_{10mm}
Horizontaal: schaaldeel 200 μs
Verticaal: schaaldeel 8 kN



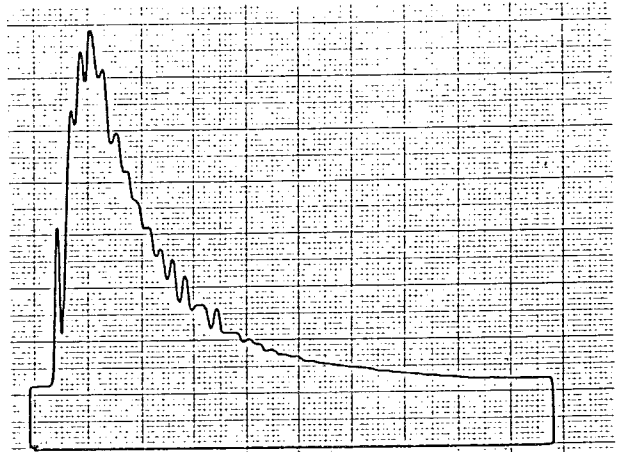
T=20°C



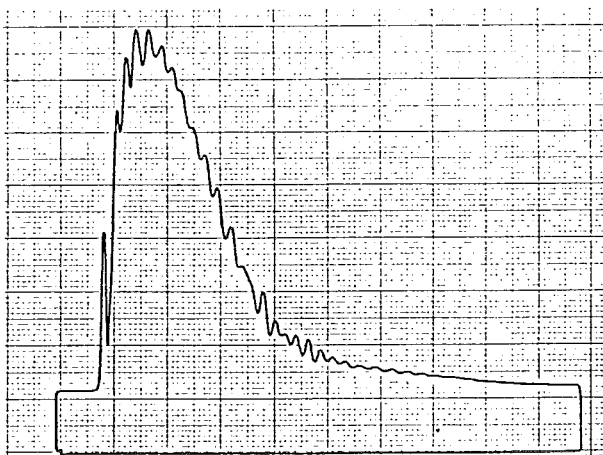
T=20°C



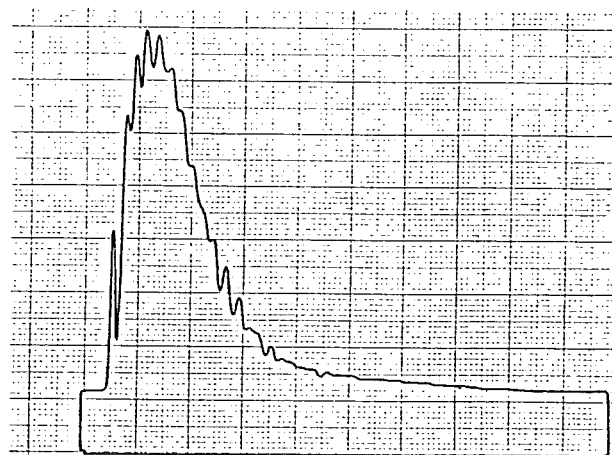
T=20°C



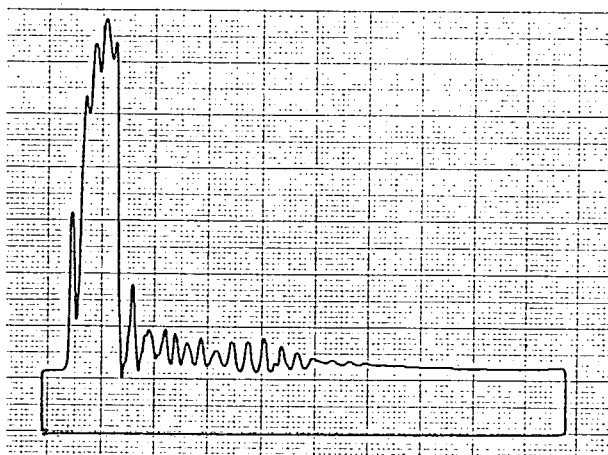
T=-20°C



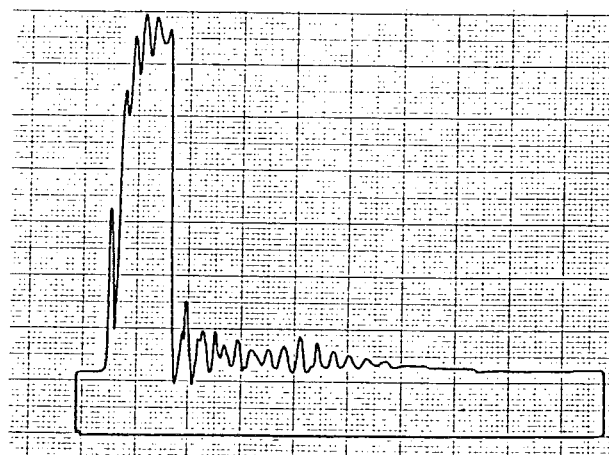
$T = -20^{\circ}\text{C}$



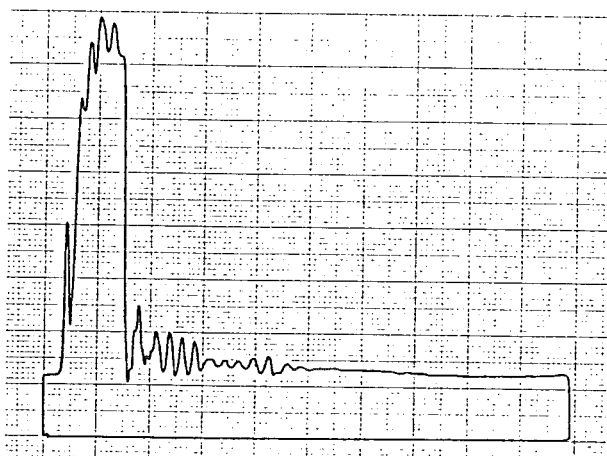
$T = -20^{\circ}\text{C}$



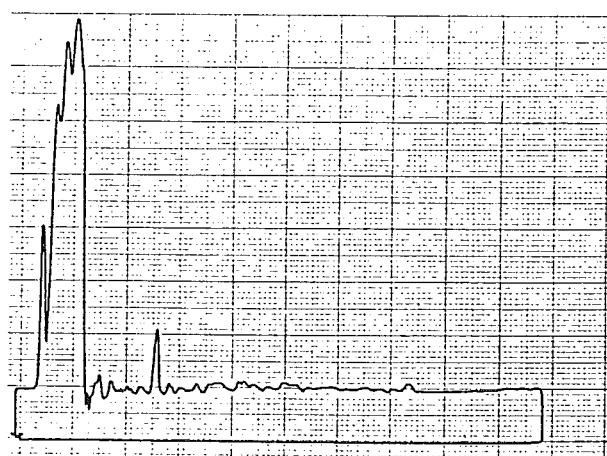
$T = -40^{\circ}\text{C}$



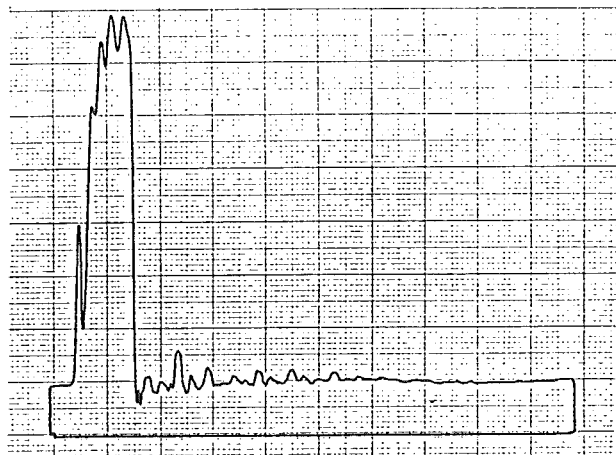
$T = -40^{\circ}\text{C}$



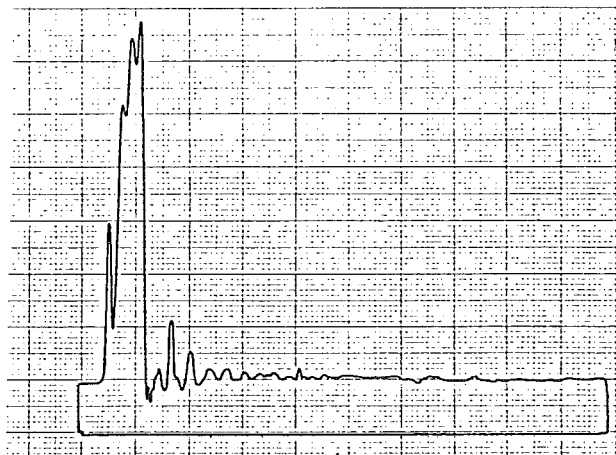
$T = -40^{\circ}\text{C}$



$T = -60^{\circ}\text{C}$

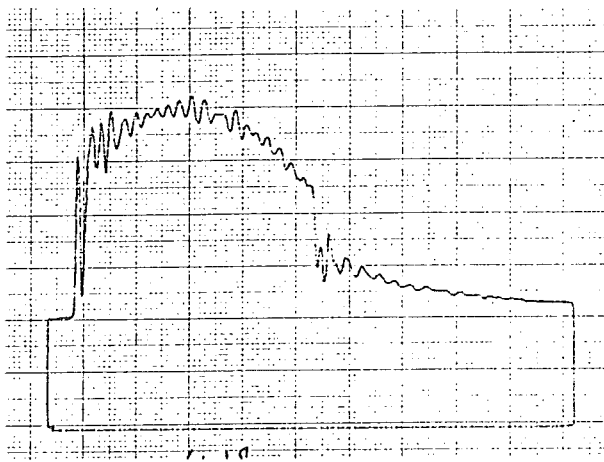


$T = -60^{\circ}\text{C}$

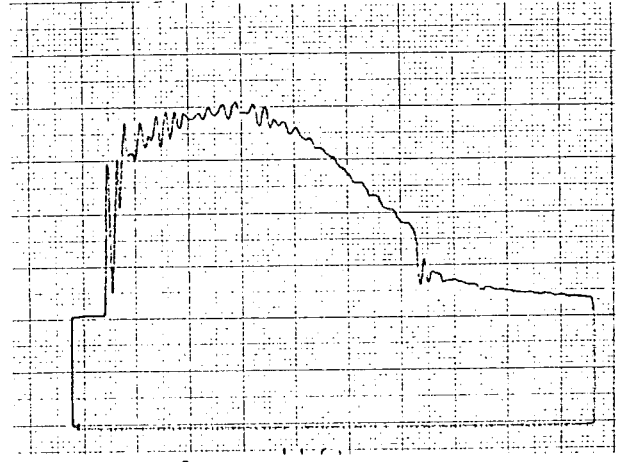


$T = -60^{\circ}\text{C}$

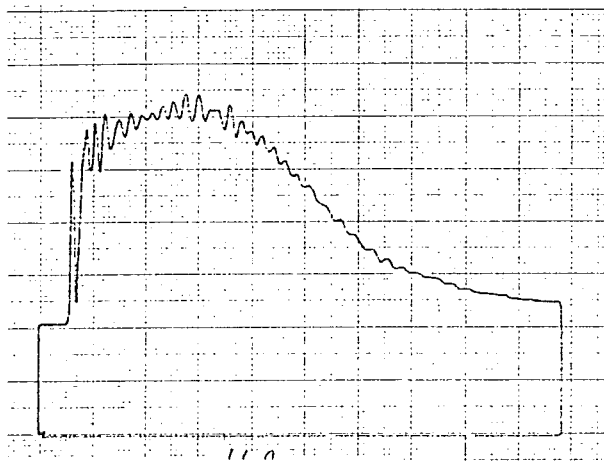
Materiaal: 41CrS4-V¹⁰
Proefstuk: U_{10mm}
Vericaal: schaaldeel 8 kN



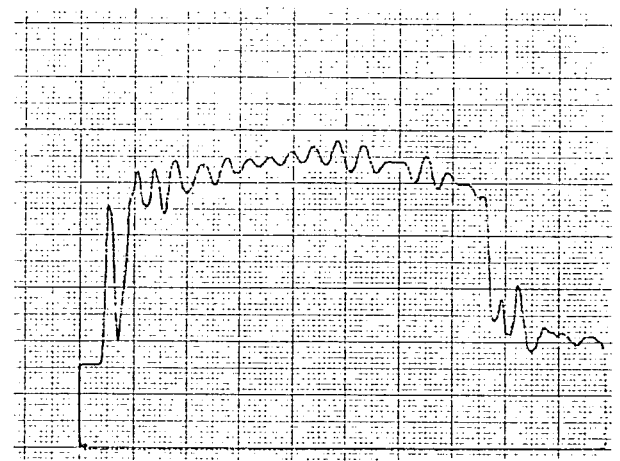
T=20°C, hor. 200 μs/schaaldeel



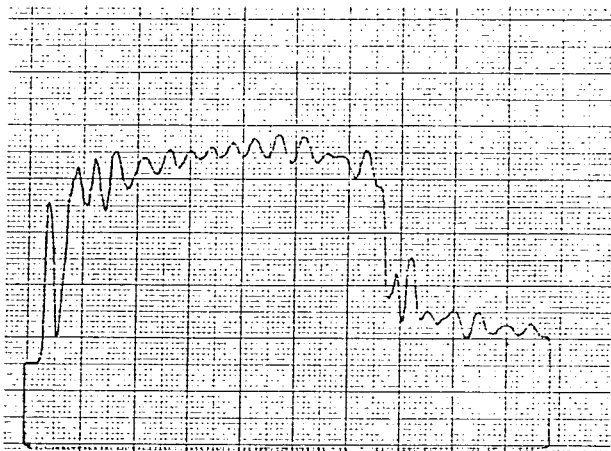
T=20°C, 200 μs/s.d.



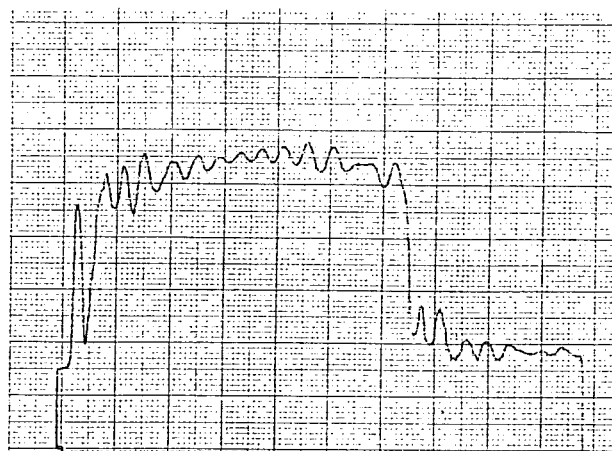
T=20°C, 200 μs/s.d.



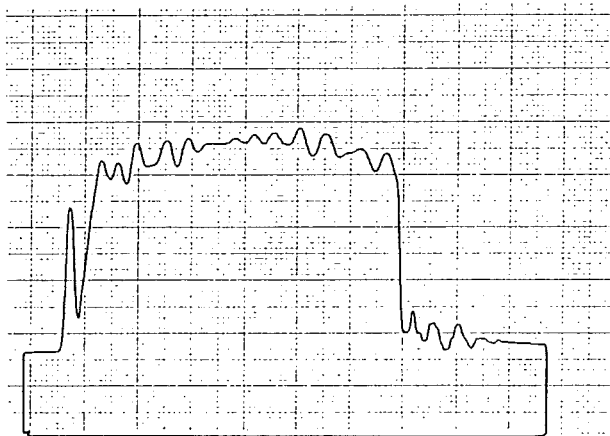
T=0°C, 100 μs/s.d.



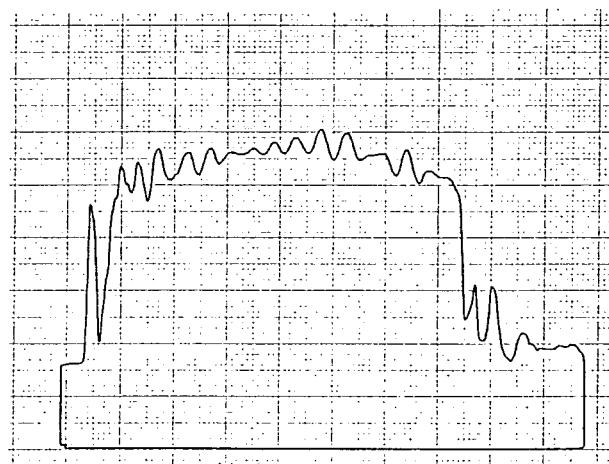
$T=0^{\circ}\text{C}$, $100\ \mu\text{s/s.d.}$



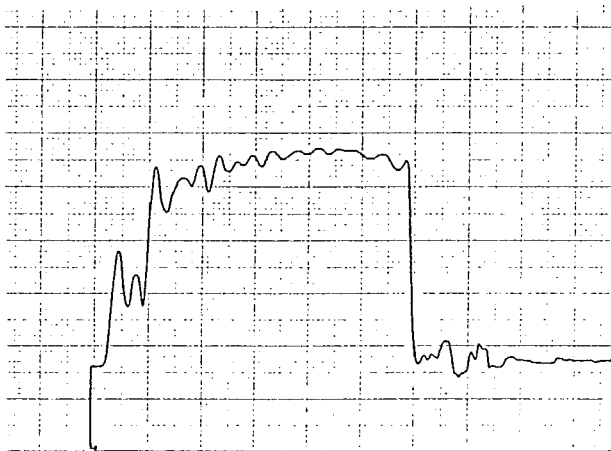
$T=0^{\circ}\text{C}$, $100\ \mu\text{s/s.d.}$



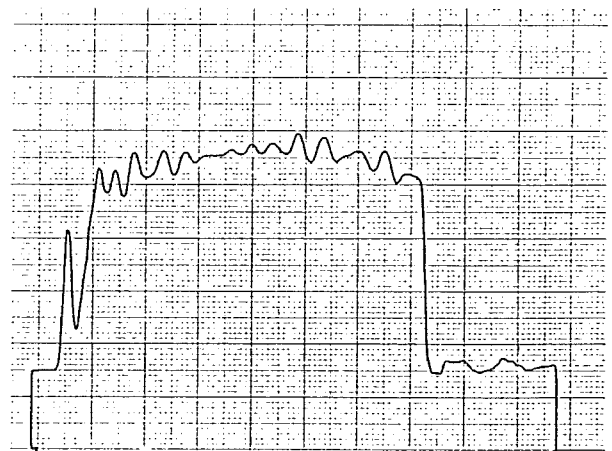
$T=-20^{\circ}\text{C}$, $100\ \mu\text{s/s.d.}$



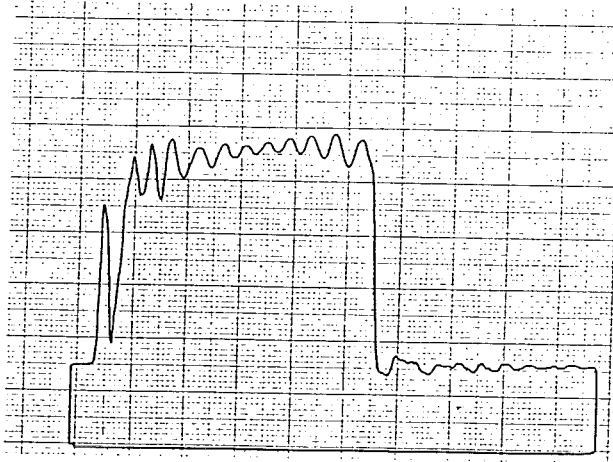
$T=-20^{\circ}\text{C}$, $100\ \mu\text{s/s.d.}$



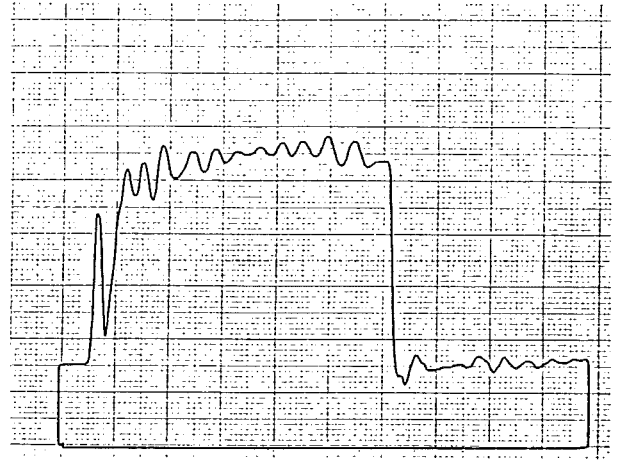
$T=-20^{\circ}\text{C}$, $100\ \mu\text{s/s.d.}$



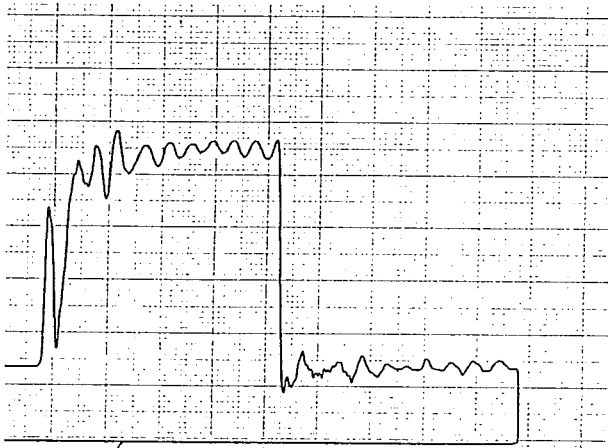
$T=-40^{\circ}\text{C}$, $100\ \mu\text{s/s.d.}$



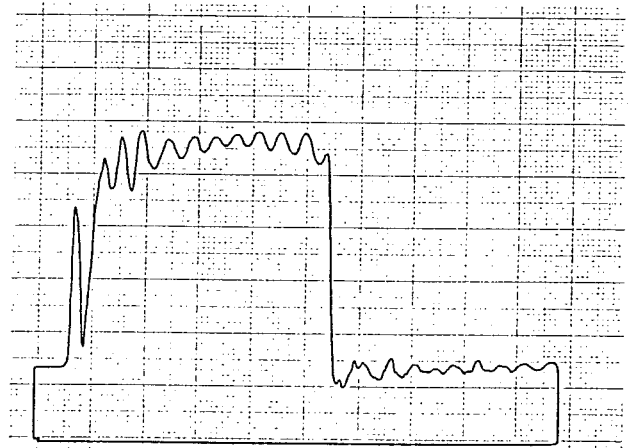
$T = -40^{\circ}\text{C}$, $100 \mu\text{s/s.d.}$



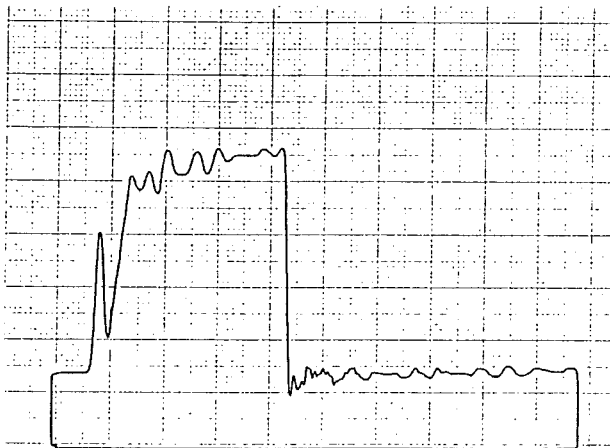
$T = -40^{\circ}\text{C}$, $100 \mu\text{s/s.d.}$



$T = -60^{\circ}\text{C}$, $100 \mu\text{s/s.d.}$

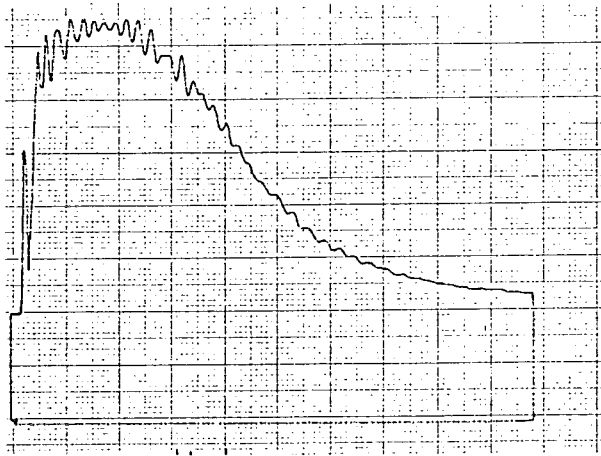


$T = -60^{\circ}\text{C}$, $100 \mu\text{s/s.d.}$

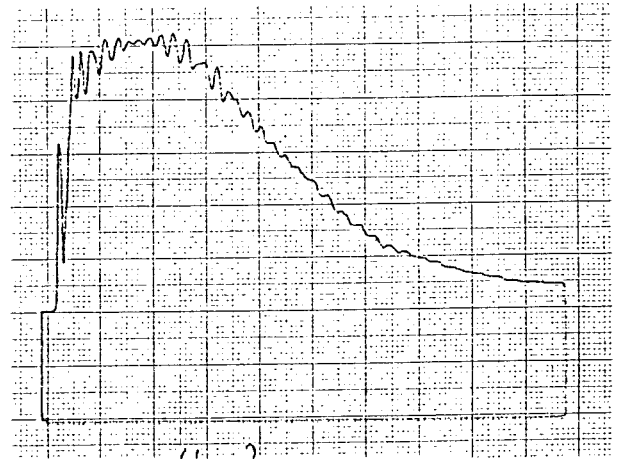


$T = -60^{\circ}\text{C}$, $100 \mu\text{s/s.d.}$

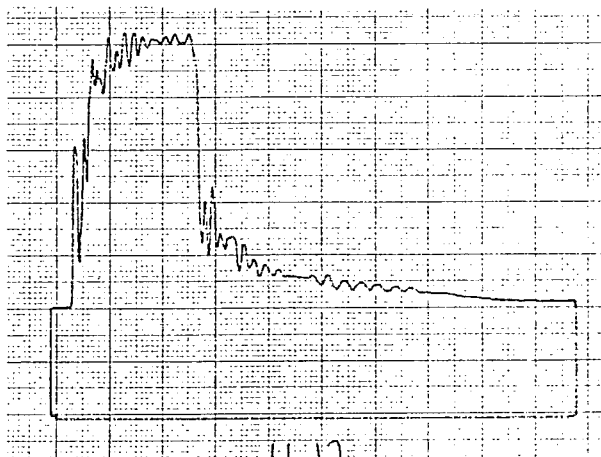
Materiaal: 41CrS4-V¹⁰
Proefstuk: V_{10mm}
Vericaal: schaaldeel 8 kN



T=20°C, hor. 200 μs/schaaldeel



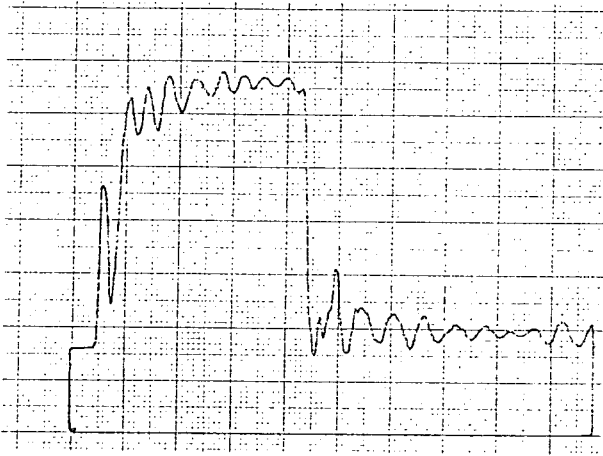
T=20°C, 200 μs/s.d.



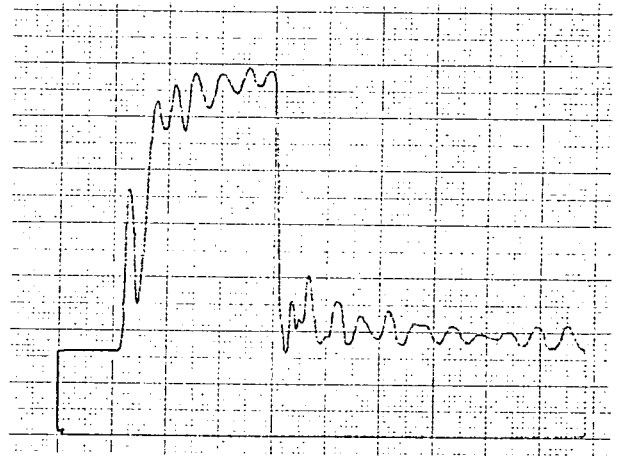
T=20°C, 200 μs/s.d.



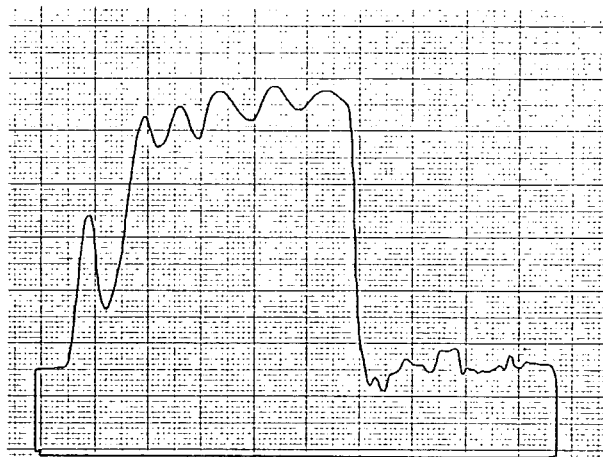
T=0°C, 100 μs/s.d.



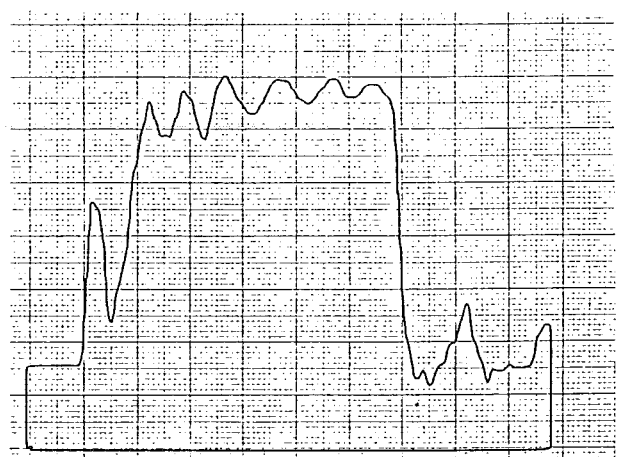
$T=0^{\circ}\text{C}$, $100\ \mu\text{s/s.d.}$



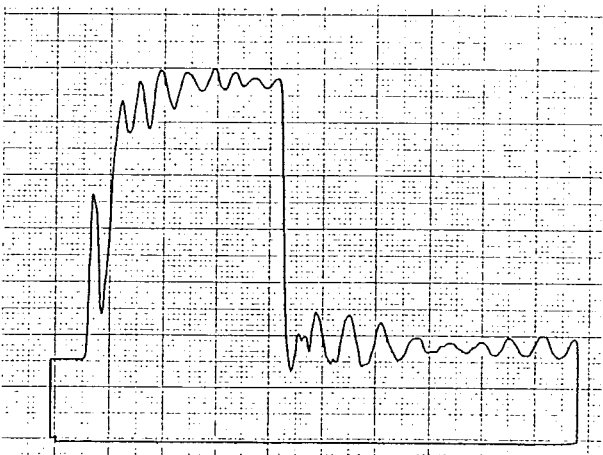
$T=0^{\circ}\text{C}$, $100\ \mu\text{s/s.d.}$



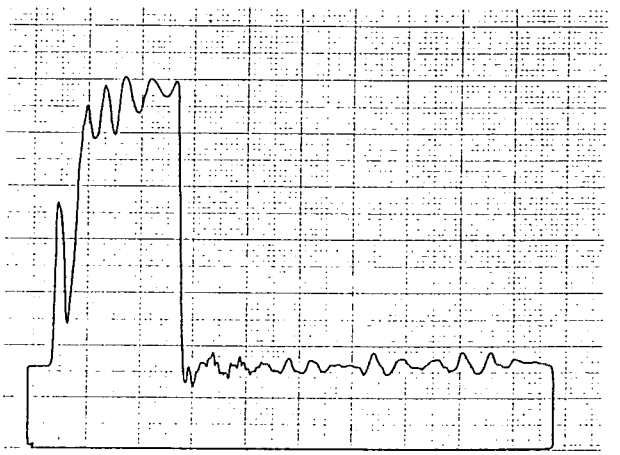
$T=-20^{\circ}\text{C}$, $50\ \mu\text{s/s.d.}$



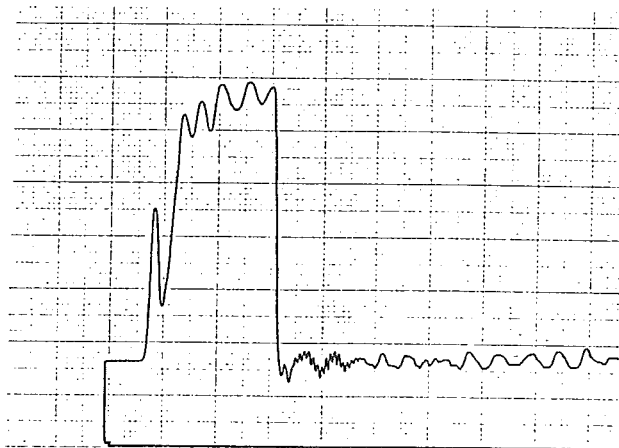
$T=-20^{\circ}\text{C}$, $50\ \mu\text{s/s.d.}$



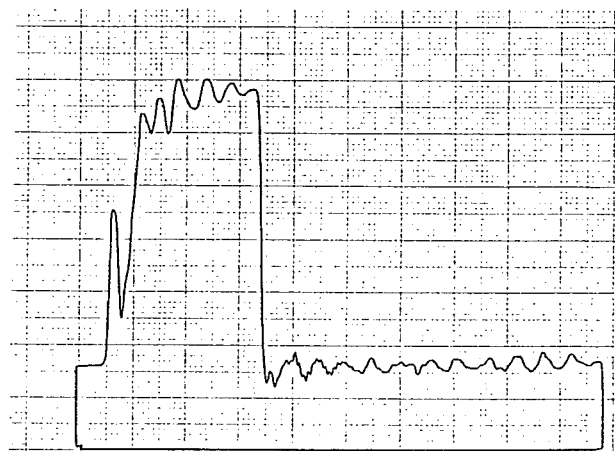
$T=-20^{\circ}\text{C}$, $100\ \mu\text{s/s.d.}$



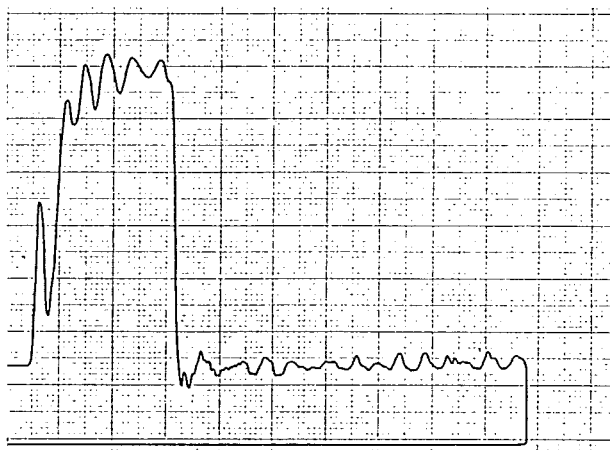
$T=-40^{\circ}\text{C}$, $100\ \mu\text{s/s.d.}$



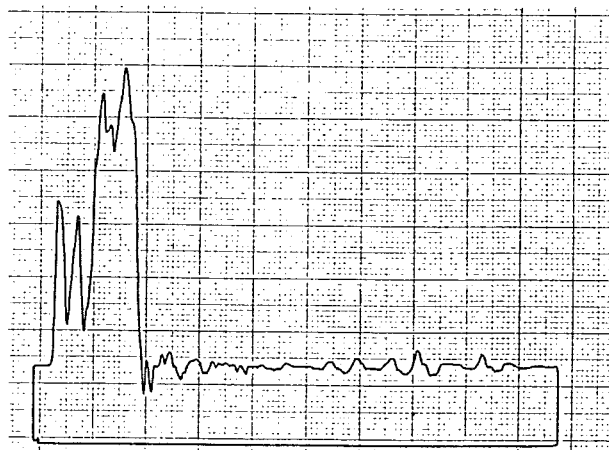
$T = -40^{\circ}\text{C}$, $100\ \mu\text{s/s.d.}$



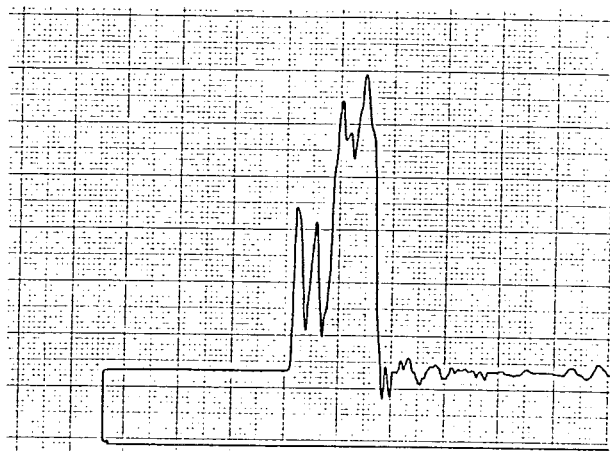
$T = -40^{\circ}\text{C}$, $100\ \mu\text{s/s.d.}$



$T = -60^{\circ}\text{C}$, $100\ \mu\text{s/s.d.}$

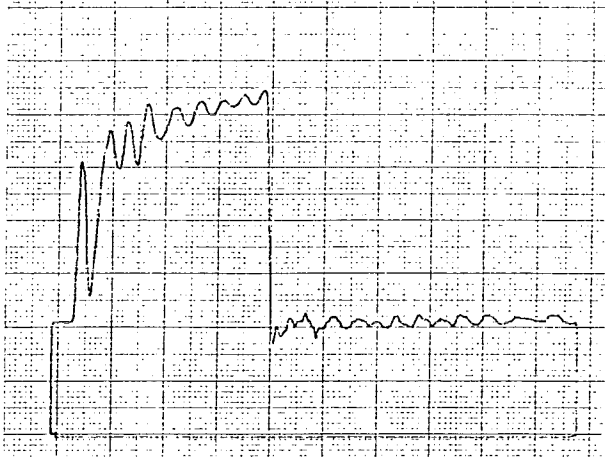


$T = -60^{\circ}\text{C}$, $100\ \mu\text{s/s.d.}$

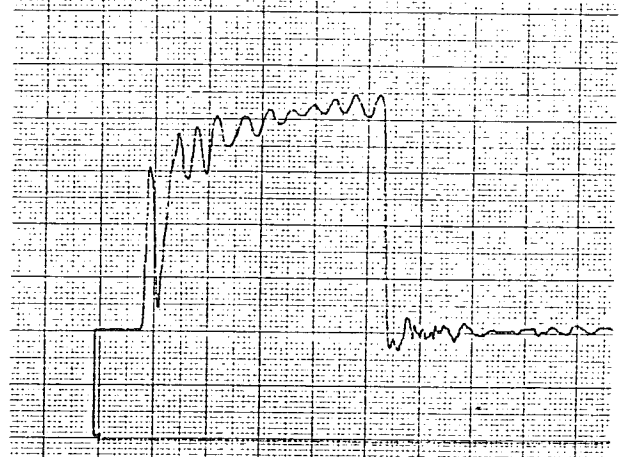


$T = -60^{\circ}\text{C}$, $100\ \mu\text{s/s.d.}$

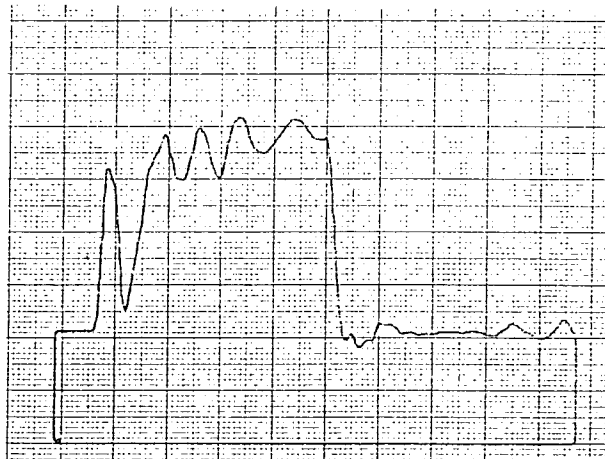
Materiaal: 38MnSiVS5-BY
Proefstuk: U_{10mm}
Vericaal: schaaldeel 8 kN



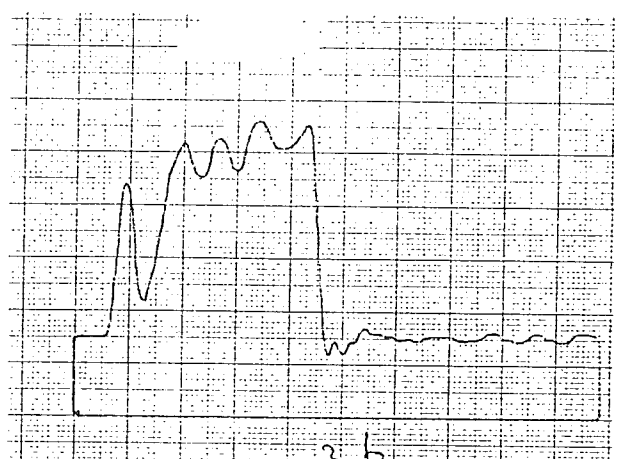
$T=20^{\circ}\text{C}$, hor. $100\ \mu\text{s/schaaldeel}$



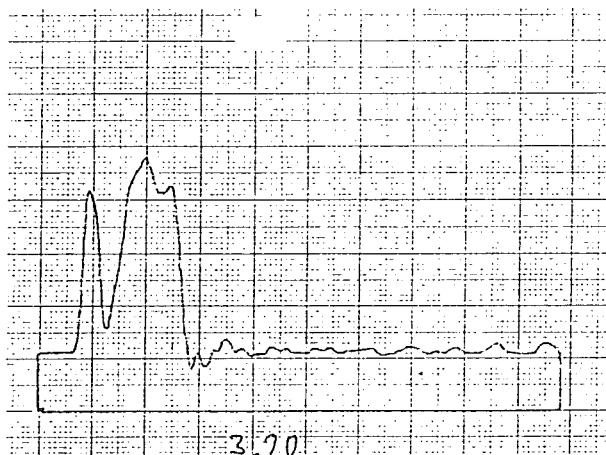
$T=20^{\circ}\text{C}$, $100\ \mu\text{s/s.d.}$



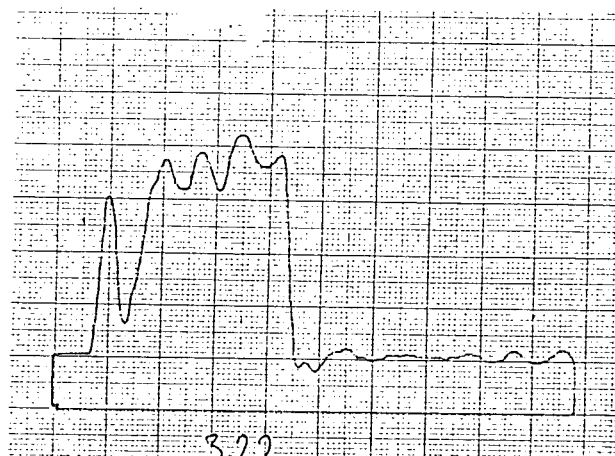
$T=20^{\circ}\text{C}$, $50\ \mu\text{s/s.d.}$



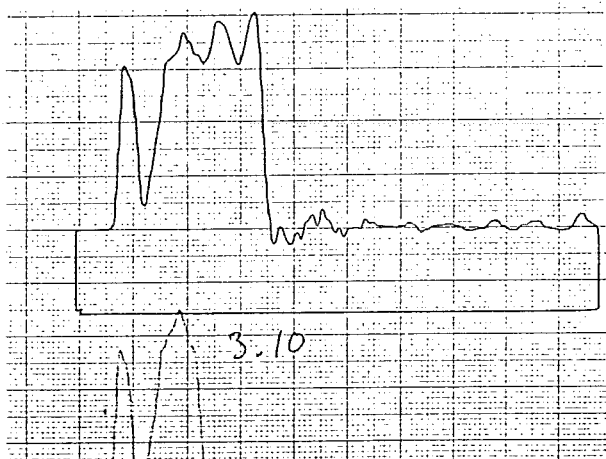
$T=0^{\circ}\text{C}$, $50\ \mu\text{s/s.d.}$



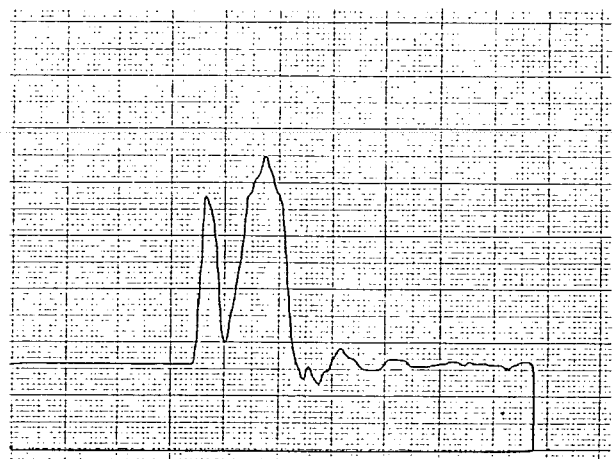
$T=0^{\circ}\text{C}$, $50\ \mu\text{s/s.d.}$



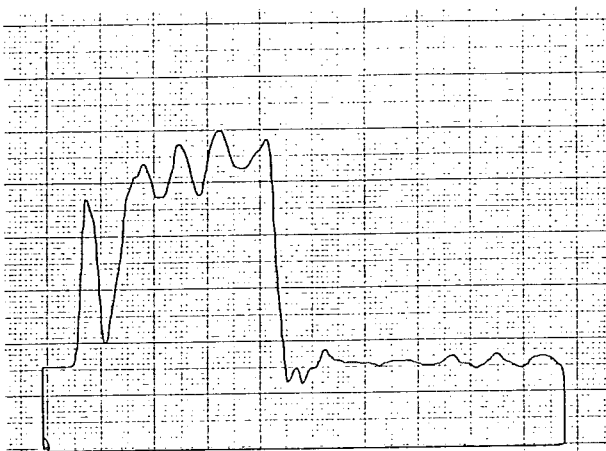
$T=0^{\circ}\text{C}$, $50\ \mu\text{s/s.d.}$



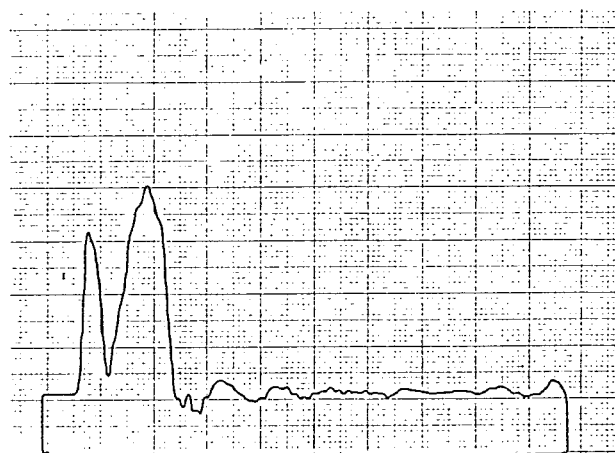
$T=-20^{\circ}\text{C}$, $50\ \mu\text{s/s.d.}$



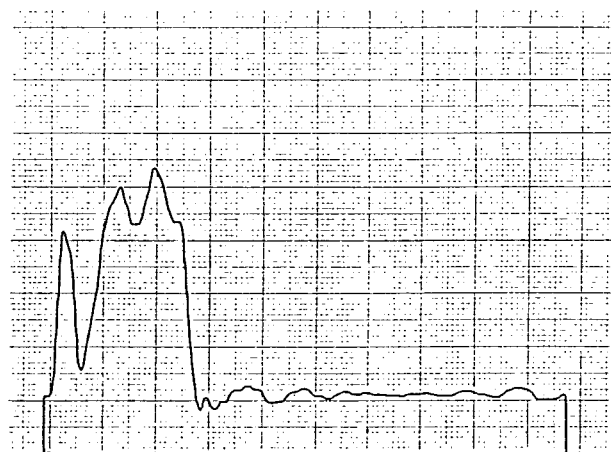
$T=-20^{\circ}\text{C}$, $50\ \mu\text{s/s.d.}$



$T=-20^{\circ}\text{C}$, $50\ \mu\text{s/s.d.}$



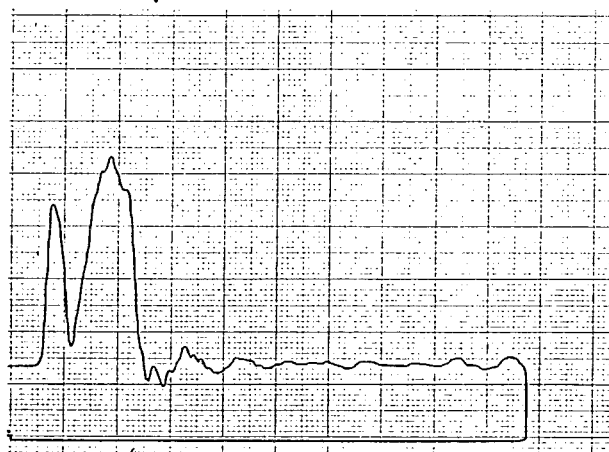
$T=-40^{\circ}\text{C}$, $50\ \mu\text{s/s.d.}$



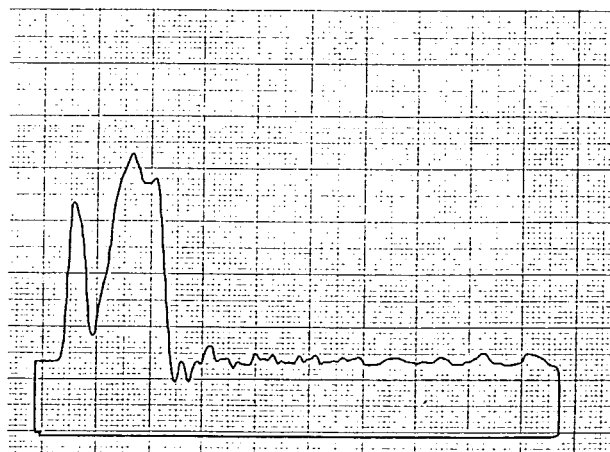
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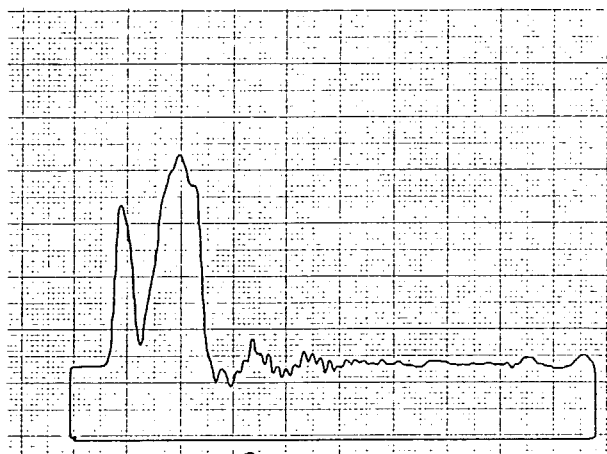
$T = -40^{\circ}\text{C}$, $50 \mu\text{s/s.d.}$



$T = -60^{\circ}\text{C}$, $50 \mu\text{s/s.d.}$

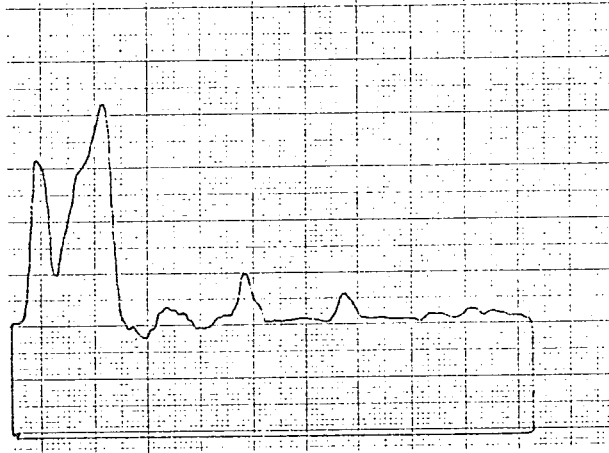


$T = -60^{\circ}\text{C}$, $50 \mu\text{s/s.d.}$

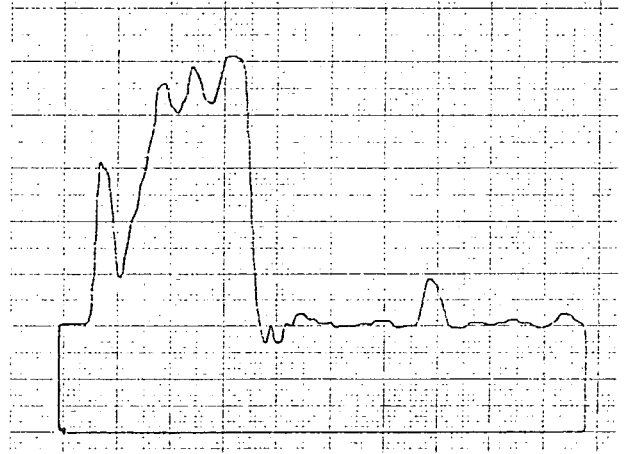


$T = -60^{\circ}\text{C}$, $50 \mu\text{s/s.d.}$

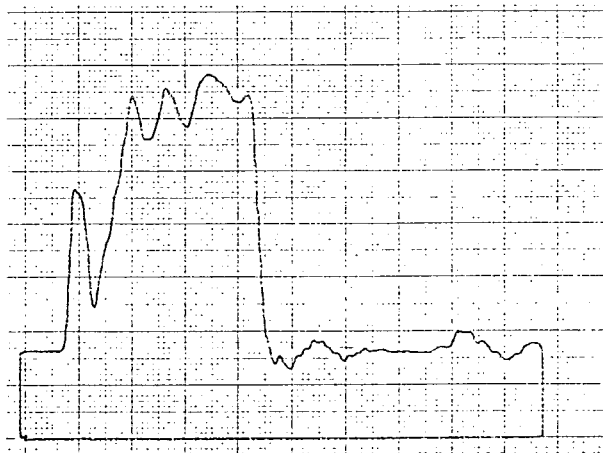
Materiaal: 38MnSiVS5-BY
Proefstuk: $V_{10\text{mm}}$
Vericaal: schaaldeel 8 kN



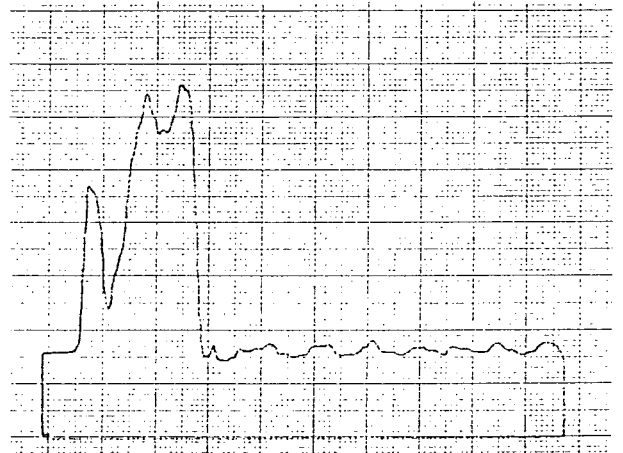
$T=20^{\circ}\text{C}$, hor. $50\ \mu\text{s/schaaldeel}$



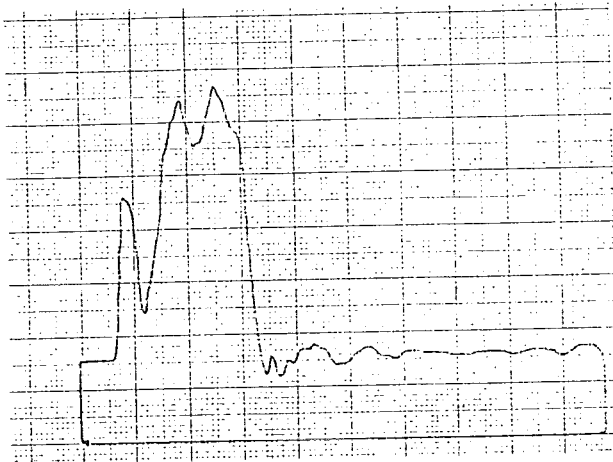
$T=20^{\circ}\text{C}$, $50\ \mu\text{s/s.d.}$



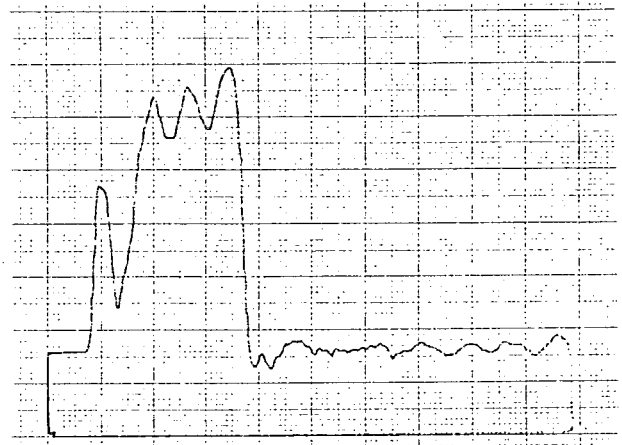
$T=20^{\circ}\text{C}$, $50\ \mu\text{s/s.d.}$



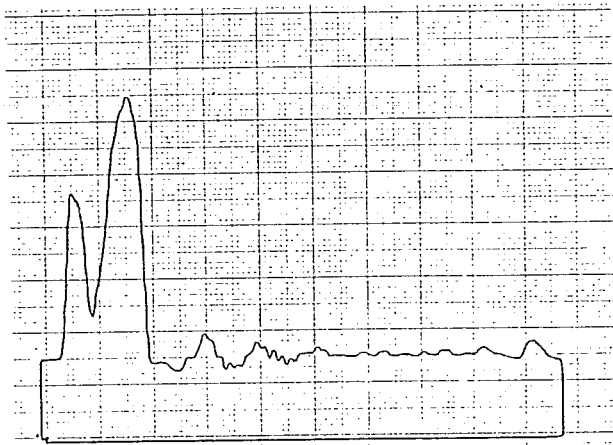
$T=0^{\circ}\text{C}$, $50\ \mu\text{s/s.d.}$



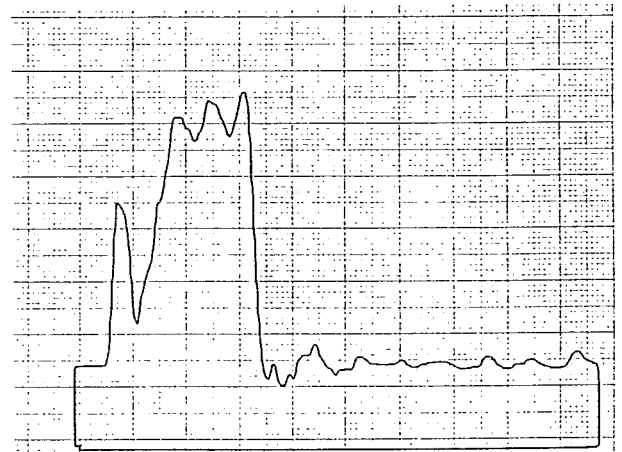
$T=0^{\circ}\text{C}$, $50\ \mu\text{s/s.d.}$



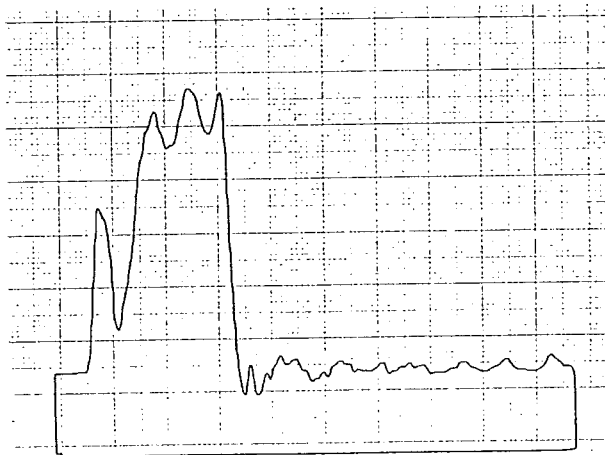
$T=0^{\circ}\text{C}$, $50\ \mu\text{s/s.d.}$



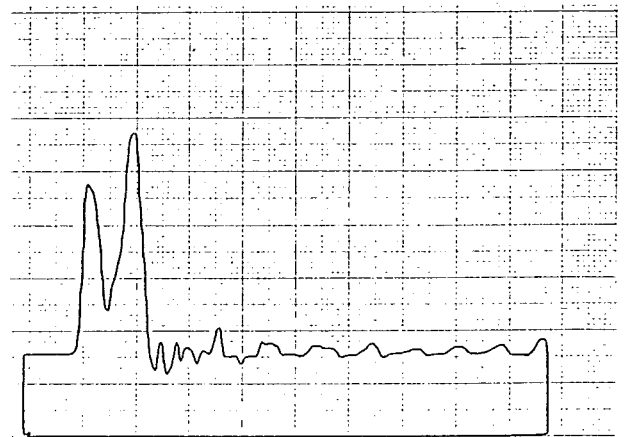
$T=-20^{\circ}\text{C}$, $50\ \mu\text{s/s.d.}$



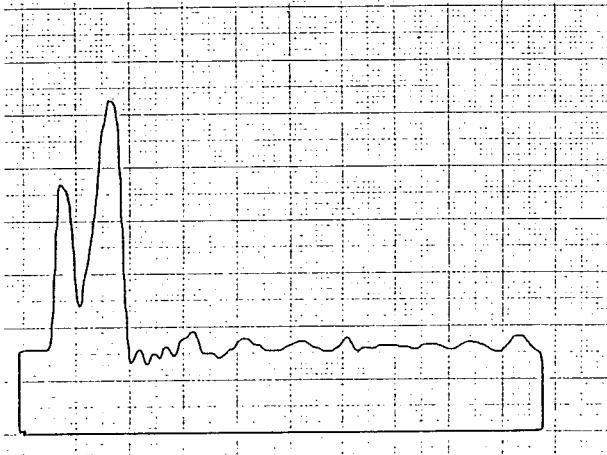
$T=-20^{\circ}\text{C}$, $50\ \mu\text{s/s.d.}$



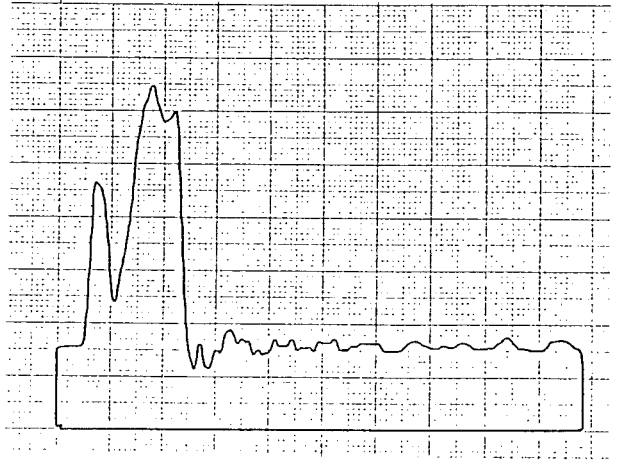
$T=-20^{\circ}\text{C}$, $50\ \mu\text{s/s.d.}$



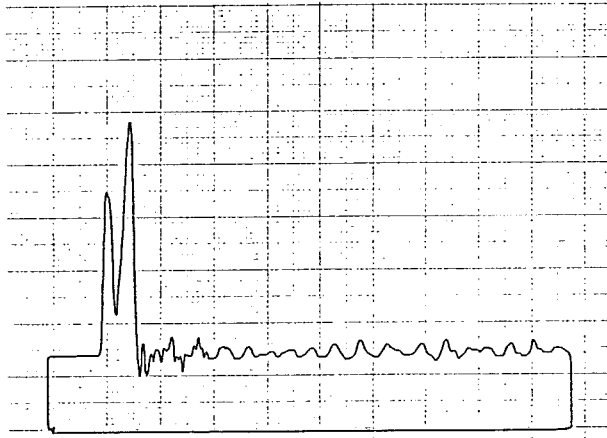
$T=-40^{\circ}\text{C}$, $50\ \mu\text{s/s.d.}$



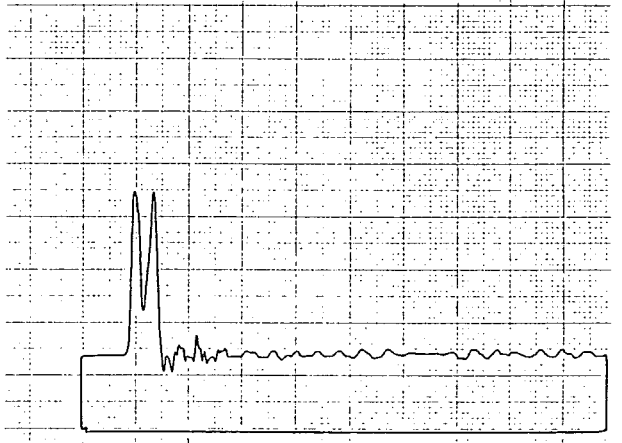
$T = -40^{\circ}\text{C}$, $50\ \mu\text{s/s.d.}$



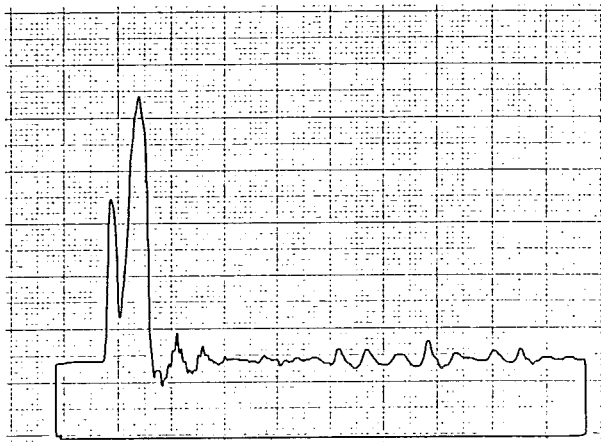
$T = -40^{\circ}\text{C}$, $50\ \mu\text{s/s.d.}$



$T = -60^{\circ}\text{C}$, $100\ \mu\text{s/s.d.}$



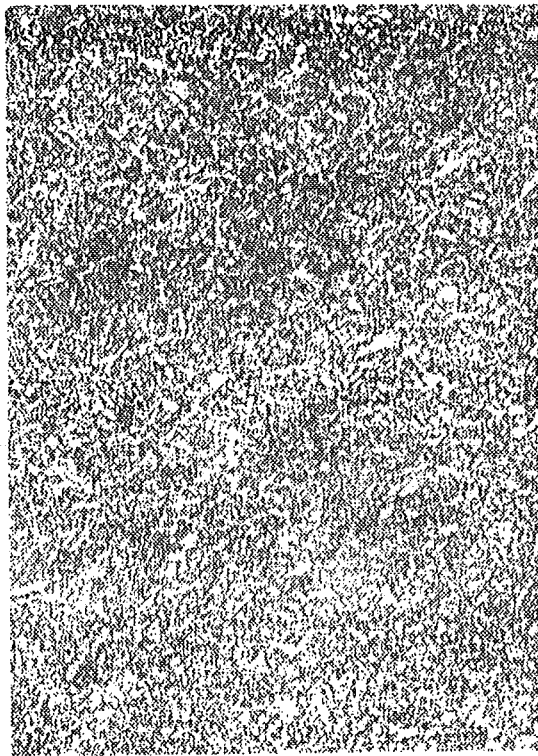
$T = -60^{\circ}\text{C}$, $100\ \mu\text{s/s.d.}$



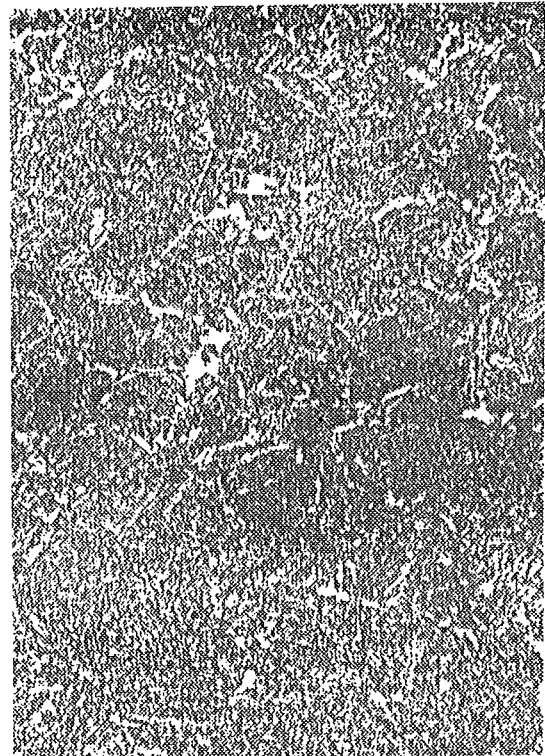
$T = -60^{\circ}\text{C}$, $100\ \mu\text{s/s.d.}$

APPENDIX 6: STRUCTUURONDERZOEK EN BREUKVLAKONDERZOEK

Structuur van 41CrS4

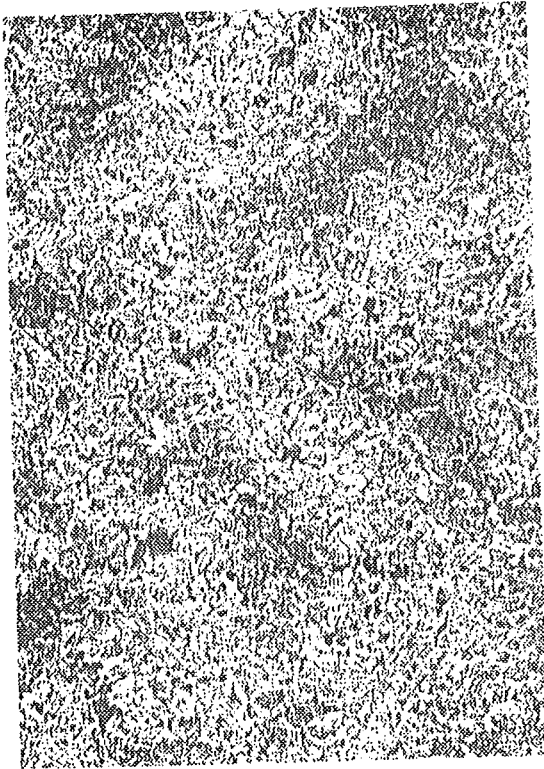


200x

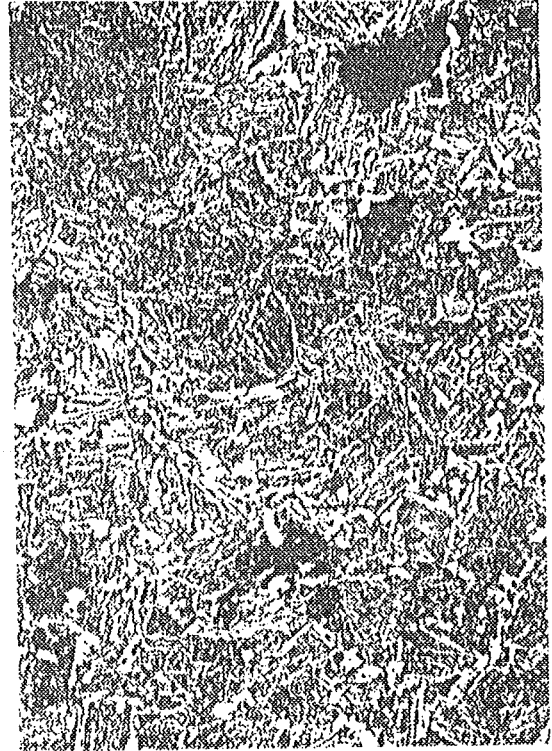


500x

Afb. 1: Veredelingsstructuur van 41CrS4-V. Dit zijn opnamen van een 30 mm breed proefstuk aan de zijde die het meest aan de buitenkant van het stafmateriaal heeft gelegen. Men onderscheidt voornamelijk sorbiet (vervaagde kubische martensiet met globulaire cementiet) en een kleine hoeveelheid ferriet. Ferriet en globulaire cementiet kunnen door diffusie van koolstof uit martensiet ontstaan tijdens het ontlaten.



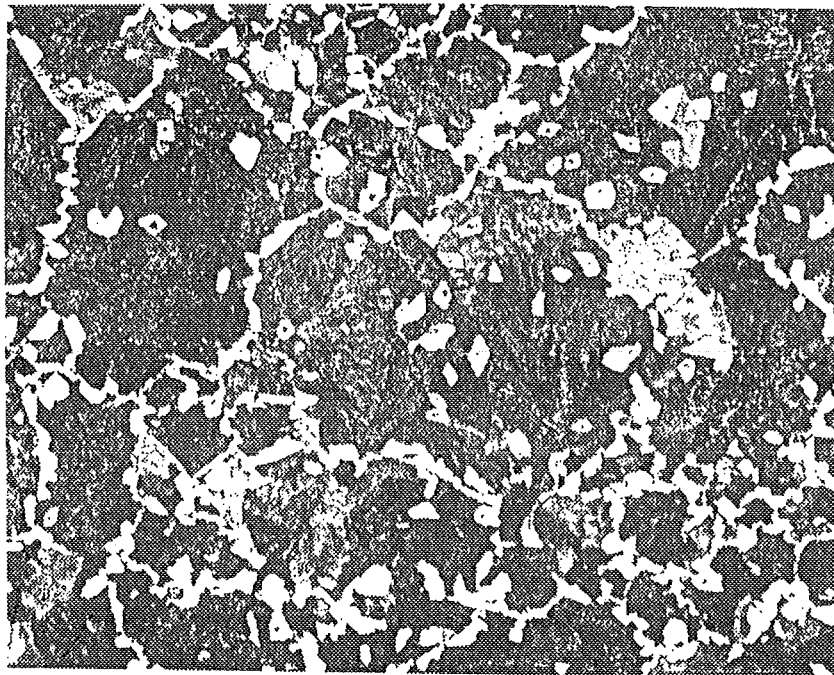
200x



500x

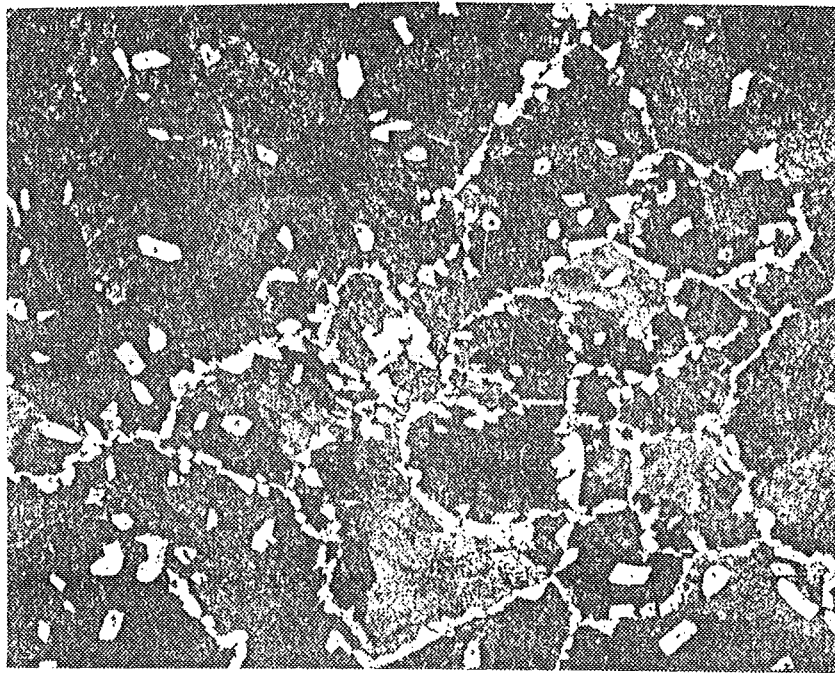
Afb. 2: Veredelingsstructuur van 41CrS4-V. Deze opnamen zijn aan de zijde van het proefstuk gemaakt die het meest in de buurt van de kern van het stafmateriaal heeft gelegen. Omdat hier de afkoelsnelheid lager geweest is, kan men hier naast sorbiet en ferriet ook bainiet (naaldvormige structuur) onderscheiden.

Structuur van 38MnSiVS5-BY



200x

Afb. 3: BY-structuur van 38MnSiVS5. De structuur is ferritisch-perlitisch. Het ferriet scheidt zich tijdens de gecontroleerde afkoeling als eerste uit op de austenietkorrelgrenzen. Bij het bereiken van de eitectische temperatuur wordt de rest van het austeniet omgezet in perliet. Het ferriet vindt men dan ook voornamelijk op de voormalige austenietkorrelgrenzen. Ook de aanwezige Mangaan-sulfiden worden omringd door kleine ferrietkorrels.



200x

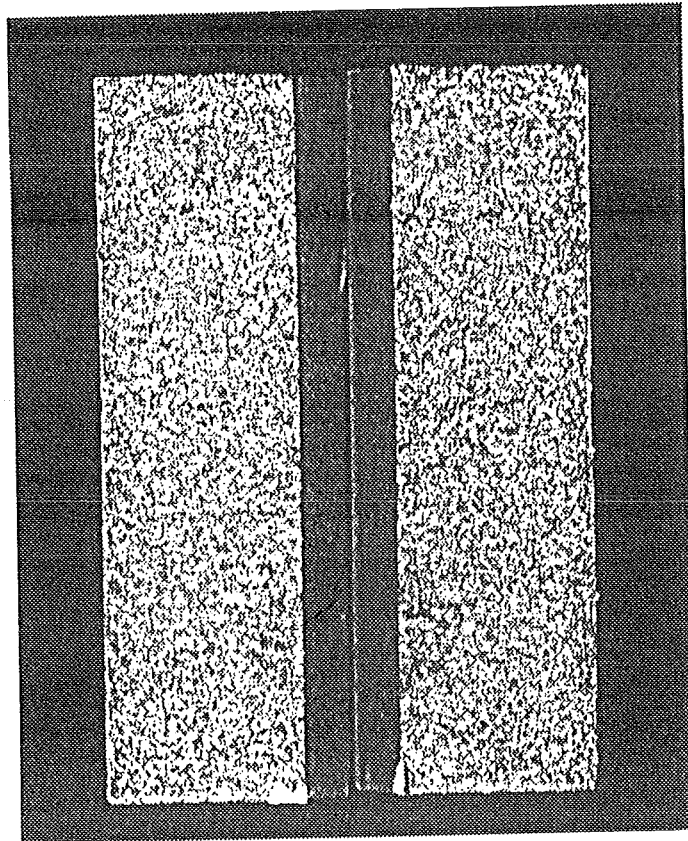
Afb. 4: BY-structuur van 38MnSiVS5. Deze opname is van hetzelfde proefstuk als de vorige, maar is aan de andere kant gemaakt. De structuur vertoont geen wezenlijke verschillen over de breedte van het proefstuk.



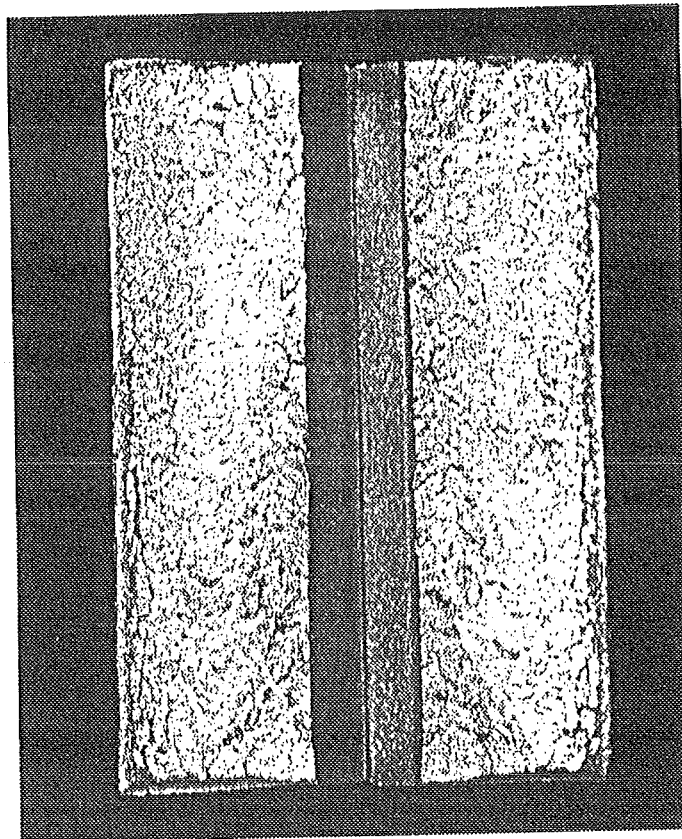
1000x

Afb. 5: Opname van lamellaire perliet in 38MnSiVS5-BY. Duidelijk zijn de afwisselende ferriet- en cementiet-lamellen te onderscheiden.

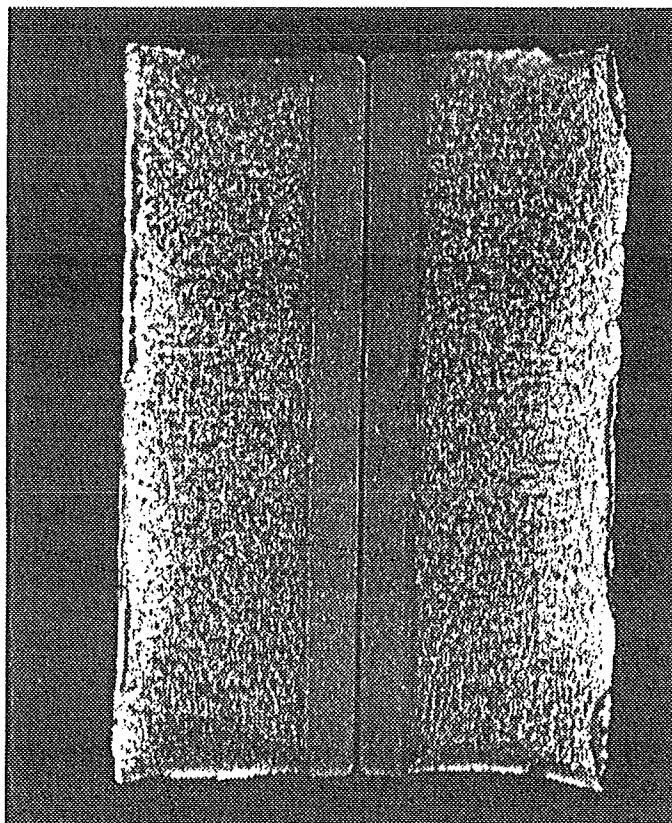
Macroscopisch breukvlakonderzoek



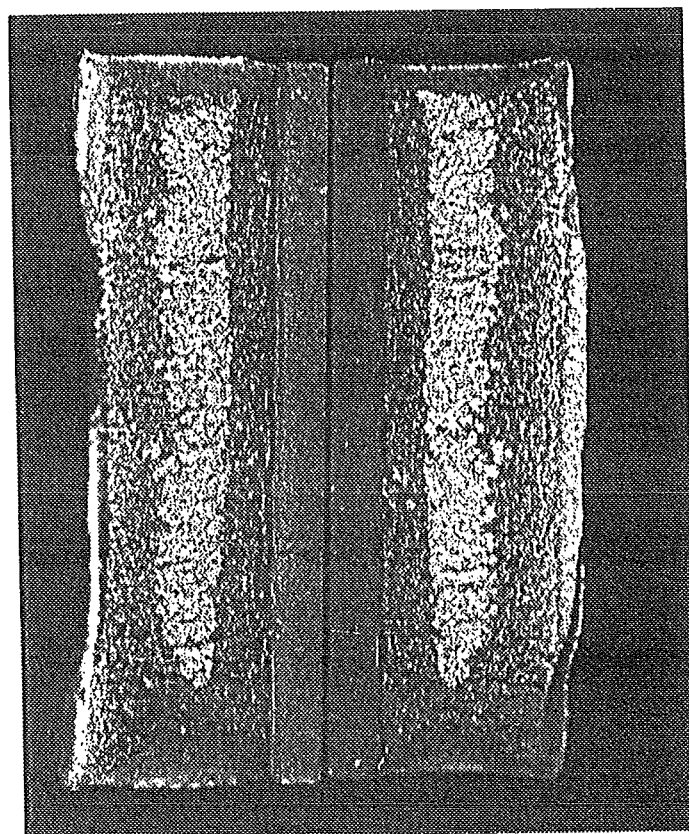
Afb. 6: Beide zijden van het breukvlak van een proefstuk van 38MnSiVS5-BY. Het breukvlak is geheel vlak en glinsterend, wat duidt op brosse scheurinitiatie en -uitbreiding. Dit is karakteristiek voor alle breukvlakken van deze staalsoort.



Afb. 7: Glinsterend en vlak breukvlak van 41CrS4-V. Evenals bij 38MnSiVS5-BY duidt dit op zowel brosscheurinitiatie als -propagatie.

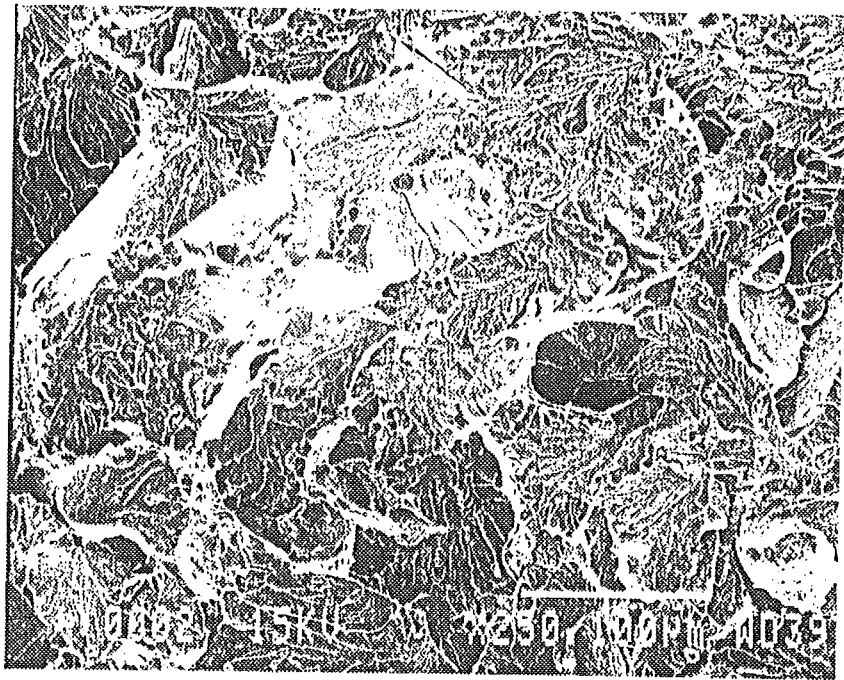


Afb. 8: Een volledig donker, mat breukvlak van 41CrS4-V. Aan de zijkanten van het proefstuk zijn kleine shearlips gevormd. Er is sprake van een volledig taaie breuk.



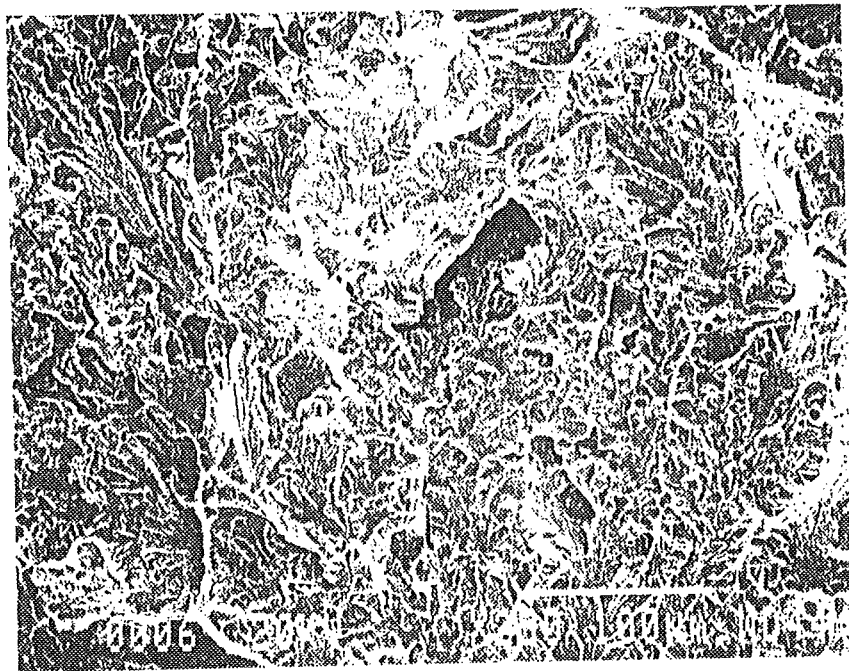
Afb. 9: Dit breukvlak bestaat uit twee fasen: de glinsterende (zie ook foto 7) wordt omringd door de matte fase (zie ook foto 8). Het uiterlijk van dit breukvlak duidt op taaie scheurinitiatie, gevolgd door een brosse restbreuk.

Microscopisch breukvlakonderzoek



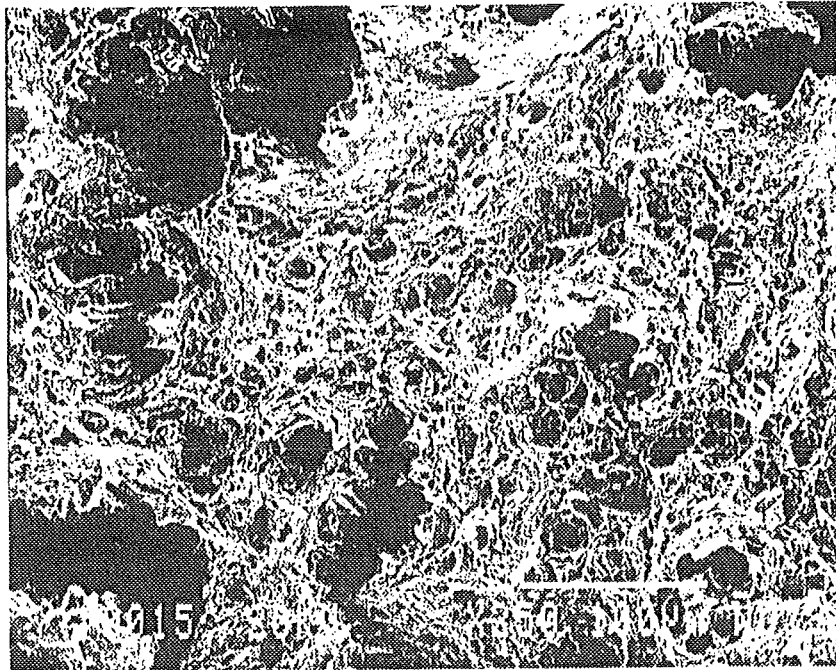
250x

Afb. 10: SEM-opname van het breukvlak van 38MnSiVS5-BY (afb. 6). Het karakteristieke uiterlijk van een breukvlak veroorzaakt door brosse splijtbreuk.



250x

Afb. 11: SEM-opname van het breukvlak uit afb. 7. Het breukvlak heeft hetzelfde brossje uiterlijk als dat van 38MnSiVS5-BY, zij het dat de fijnere microstructuur van 41CrS4-V een iets fijner breukvlak veroorzaakt.



250x

Afb. 12: Een taai breukvlak van 41CrS4-V. De vezelachtige structuur is kenmerkend voor een taai scheurinitiatie en -propagatie.



50x

Afb. 13: De overgang van taaie naar brosse scheuruitbreiding van het proefstuk uit afbeelding 9 is op deze SEM-opname duidelijk waar te nemen. De scheurinitiatie en het begin van de scheurpropagatie zijn taaie. Bij een bepaalde scheurlengte is de scheur bros verder gegroeid.