

7KH VWUXFWXUH DQG IRUPDWLRQ
FRDWLQJV D VKRUW UHYLHZ

Vlad 'LFFXDQJ .D]HN . VLN

7HFKQLFDO RQXPHVWV FRDWLQJ FRDWLQJ DUH
)DFXVWKHPLVWU\QBYLHVLVQSRQDQ

\$EVWUDXWQLQJ WRROV KBBHMLQGLIVHJHGWHRPHWU\ E
PDWHULDO DQG FRDWLQJUVDFFRVULQDQWDRQVFIH\ DUH
ERWK IRU REWDLQLDFJKSDDEVLQIDVQDSHRUVDVVKQDUWKLV S
UHYLHZ DERXW KLJK VSHHG VWHHOWHQVWXUQLQJ W
SUHVHQWHG +DUCFRDWLQJWRORRQDQDFULDRQDORXOG EH
GSHHQGLQJ RQ WKDWLRQDSHQDQDFRSDQVVRDQSDUG
WHFKQRORJLFDQ SIURRUPDWLQRQRQVWHQDHDQDFXWWLQJ
GLVFXVVHG

7HFKQLTXHV DQG SURGXFWLRQ RI KDUG FRDWLQJ

,Q D VWDWLWVLFDO VWXG\ PDGH ORLQVQK 'HODUDUV HV
LQGXVWU\ RI FXWWLQJ WRROV LQFOXGH WXUQLQJLQJLQJ
DQ DQQXDO JURZWK DVVXPHG WR EH Q RKHVQDFDVMV
FXWWLQJ WRRO VXEVDWV LV UHSUHVHWHWVHGFDEVFVHEH
VSHHG VWHHO +66

&RDWLQJV RQ FXWWLQJ WRROV DUHQZLVKH\SSURYDGH
WKH FXWWLQJ SURFHVV ,Q WKH+66DURROVIVPRGFHVDWEL
DQG RI VXSHU KDUG WRROV XVHG LQ LQGXVWU\ ZHU
SKHQRPHQRORJ\ ZLFLK DFFRPSDQLHV WLQHVLQVHVVXV
FRDWLQJV RI +66 WXUQLQJ WRROV ZLOO EH WUHDWHG

7KH XVH RI FRDWLQJVLHQB [SHEHVVWVHUVRROVDBWLQJ
DQG DGKHLVRQ GLIIXVLRR [LGDWLURQVDBQDWRHSDVRGK
IURP WKH FXWWLQJ DUHD LQWR QWKSIURRQRVPLDYLWU LDDG
+RZHYHU UHJDUGLQJ WKH KHDW LQD\KQDWLRIQ SVKSHBS
SURYHQ WKDW VQVHQRDXLQJWVIRIDRWRROVXIDWHQVWKID

ODLQO\ GSHHQGLQJ RQ WKH PHWKQRDPEIQFRDWK HQBDRV
DSSOLHG WR ERWK +66 DQG FDUELGHV DQRYDQW DJHFK
GLVDGYDQWDJHVDFWRQGLQSDSQRFDWVRFQWKKIHSRROSHVXU
EH LPSURYHG DFFRUGLQJ WKHLU QRLYJKW\SDSSQEFDWL
PDQXIDFWXULQJ SURFHVV 'HSHQGLQJYDQLRKHVWDXLQERD
EH IRUPHG RQ LWV VXUIDFH 7KH QDQSHRVIWRKSDVXDFDQ
WHFKQLTXHV OLNH SK\VLFDQ RU FKHUPDFDQRQDSRHHQSSR

&RUUHVSRQGLQJDXWFLRQDQDFRQJHN NHVLN#SROVO SO

FRDWLQJV DUH QRW ZHOO GHILQH G KEXUJG Q W/V R/LU Y VE HEMZ
 +9 7KH ILQDO PHFKDQLFD O\LSJQRLS IHFUDQVM\ RG HY
 WKHLU VWUXFWXUH SKDVH FRPSR VPHVFKRQQ IDFDGD KSUFRRSJHU
 FRDWLQJV IRUPHG RQ WKH PDWHU LDFD O\KURHXV\G\ VM DKLFEH W
 &KHPLFDO YDSRU GHSRVLWLRQ &9'9'RUDSJF\ V\IRFD O YDDV
 LRQ LPSODQWDWLRQ SODVPD HQKDQFHG FKHPLFDO Y
 VSXWWHULQJ DUH ZLGH O\ XVHG IR VLIQDU39'FV B\WKLOU\TXIHR U
 LV DOORZHG WR SOD\ ZLWK D FRELSOD W\LR QI IRI 1G L2 I HULH
 DQG LV DEOH WR REWDLQ OD\HUV RID Q-DPU Z R ZHU H DUD O
 PDWHULDOV 7L &2 1 IRZL D DQG -S WKLFN FRDWLQJ EXW I
 FRQWURO SDUDPHW H\WWD WXF KS B D W H I E R Q S W D W L V R L Q R I D F Q G V
 /LPLWDWLRQ RI &9' DQG 39' WHFKQ IHTUX B V S R V K W L K R O H X
 DURXQG f & S R K U H D D K H U L W Q W I K W P H W E L P H U D S R I R D Q D G
 EHWZHHQ LQWHUOD\HUV LQ WKH FRDOW\ QJ FUKHD WLFORJ D
 VKDSHV RI WKH WXUQLQJ WRRO ODUJ V G D S L U D V K O H I R U R U H V F
 EH KRPRJHQLJHG WKRXXJK WKH ODA H P U L J R K U W V E K I L B D Q R V G L I
 VRPH SODFHV RI WKH PDWHULDO
 7KH FRDWLQJV FDQQRW EH DOVR IEU IZV W\OHQ JG O H I H W R I
 7KXV 39' DQG &9' WHFKQLTXHV DUH JHGU D B G V P R U I F R S O D
 OD\HU PD\ EH IRUPHG RQ WKH VXEVDWUDWH E\ 39' WHFKQ
 IRU PLQLXP TXDQWLW\ FOXVWILQD W L K L O K J V S O H I G V K R X L O G
 FKHPLFDOO\ LQHUPD O S K V D D E O D H Q G K W W U H D W D I G H P R I W M K H D O Y
 VPRRWK KRPRJHQRXV FRPSDFW DQG ZHDU DQG DEUDV
 (YHQ WKRXJK FDUDELGH WRROV DUHI IPRRULF H V H G S U R I G H W
 LQ PDQ\ FXWWLQJ DSSOLFDWLRQV GXH WR WKHLU ORZ F
 IRU PLOG VWHHOV DQG GXH WR W K H U B R W K D S E L O J W S R U D V
 UH VKDUSHQLQJ RU UH VKDSLQJ R S H W L D W L R Q D P X W W R E D F K
 EHVW UHVXOWV

)RUPDWLRQ RI KDUG FRDWLQJV RQ +66

6LQJOH FHUPLF FRDWLQJ

7KH FRDWLQJV DGKHLVRQ WR WKH B H W D D Q G X B V W S R D W M H V
 WHFKQLTXHV 7\SLFDO SURWRFROLF B R V E X O D D W H L G S J H W U E
 EODVWLQJ VKRW SHQQQLQJ H W F K O B B R U R S B O R V I R L Q V H O U
 WKH VXUIDFH SUHW W I R O W P I R O W I X S U B I O H L S O B J O D H R U I R U P
 3RVW WUHDWPHQW LQFOXGHV XVXDOO\ WKHUPDO FRDW
 OD\HUV IRUPHG R B O K D J K H F S R P S G W H G R I L \$ O & >7L1@ \$ O L W D O
 EDVHG PDWHULDOV DUH FKDUDFWHUWILJHG Z H H L H X K D Z H O U U
 PDWHULDO H[KLELWV JRRG FKHPLFDQ X P Q G L W K L G U P D O V V
 RIWHQ XVHG DV D UH I H U H Q F H L Q V B H H U P D O U H Q D R O U F H G V G
 VWHS FRDWLQJ IRUPDWLRQ 'XSOH[I O D X H U D U F R I P S R R H G H
 GXH WR KLJK KDUGQHVV RI WLWD O M L X P S F D R U S H L G M L D I Q G R W W
 QLWULGH 7KH FRDWLQJV FRPSRVHG RI 7L&Q7FH&RI V W H H
 VXEVDWUDWH LQ FKORULGH HQYLURQPH Q W K L E L W P X X O W
 PHFKDQLFDO SU B S H K W D L H G Q H H W S F B K Y D W K L Q Q H Z F H B O W H D W L
 FRDWHG E\ IXQFWLRQDO PXOWLODOH U W H G D R G F PDWHUL

OXOWL0D\HU FRDWLQJ

2.2.1. Titanium-based layers

0LFURVWUXFWXUH DQG PHFKDQLFDO 7S\$Q\$HUPVWUWHU RD OF
LQYHVWLJDWHG E\ HW\$ D\$ %XNK DZ KDLO FRVWRZHG P DORZHU
FRHIILFLHQWV WKDQ ZH UDGLFKIPJDKM FRPSOG\$VWR WKH
XQFRDWHG PDWHULDOV 7KH FRDWLQJ JXWLVZHOH JORDGU
OD\HUV ZHUHQCW EULWWOH RQOLVSHLOHOD WERRUFGKLSJS W
FUDFNLQJ RU GHODPLDQFK RQH VWURLOQVXUHPHQW
7ULERORJLFDO DQG PHFKDQLFDO SURSHUHQDQJGRUWVGH W
LPSRUWDQW 'XULQJ WKH VFUDWFKHPDWV LXQJHPXHQW MVLW
DQG FKLS GHIRUPDWLRQ RI WKH OHUHQDQJ 7KHUIRUPHQV BR
WZR 30 +66 6 30 6 30 VXEVDWUWHMLZDWKHLQHMV DQ
7HPSHUDWXUH RI WKH VXEVDWUWHG ZDV LEHJWZHOLODQHU
&KHPLFDO FRPSRVLWLRQ RI WKH VXEVDWUWH VOLJKWO
PDWHULDO 7KH GLIIHUHQFH LQ WKH KIRWGGH VQ DQGXH ZD
IRU 6 30 ZKHQ FRDWLQJ DWZWHHSIRBDV KULKXJS WRHPSJU
RI WKH VXEVDWUWH GXULQJ WKH QRDWLQJ R \$QRPHVWK
PDWHULDOV +HDWLQJ RI WKH VXEVDWUWHVODVRI WQDQX
WULERORJLFDO SURSHUWLHV \$ORO WDNHUXE VWRZHWGH M [ZH
QDQRLQGHQDWLRQ WHVV 7KLFNQVXEW VRU DWKHHVFRDQV EG
QP WR DURXQG P
'HSHQGLQJ RQ WKH DSSOLHG WHFKQWV KHHVVWEN VFKIDP
VWURQJO\ LQIOXHQFH WKH ILQDO HHHFWV RI VXEVDWUWH
LQIOXHQFH RI WKH VWHHO V KDGGQ KM WRUJHE B QVKHL FDXJ
SUHVHQWHG LQ SDSHU > @
&RPSDULVRQ RI WKH PHFKDQLFDO [SURSHUWLHV ZUW
7L& 7L& 7L1 OD\HUV IRUPHQV RQH KLJKDWS SHGRWIDQWHG OE
> @ 7KH OD\HUV ZHUH IRUPHG XVL'QLRQ OSCORDZVE QWKRIO
OXOWL0D\HU FRDWLQJV VKRZHG KLJKPISDZHIGUZDQEG Q
OD\HUHG PDWHULDO +RZHYHU WKZDWXFRQVH RW MCK HZ LPV
VLQJOH OD\HU 7L1 ZKLFK H[KLEGLWXYHMFHDVHQWL D QKH
PXFKEHWWHU ZKHU PDWHUW DQDFRFRDWLQJ RYQGRPSRDWG R
FDUERQ VKRZHG WKH KLJKHVW KDUHQHVRQWKUXV6WKU
LQYHVWLJDWLRQDQMLQKWHIUPHQHUVB VOD\HU EHWZHHQ V
OD\HU ZDV UHSDUDWHDGHEX .DO > @
7KH WKLFNQHVV RI WKH ORZHU ODVWZB WKILFKHQV V
XSSHU 7L \$O 1 OD\HU P 7KH QDQUDGXHHWHI GRPRH
OD\HU ZDV FRPSRVHG RI DW RW LDVQXQLQXP GDHQGHUP
('; DQDO\VLV \$GGLWLRQ RI WKH DQXPLVQ XE FUDXVHGGW D
H[KLELWHG ORZ IULFWLRQ FRHIILFLHQWUHVVLVWDQWKHFR
DLU DW
7R HQKDQFH DGKHUVRQLRIDVBR7DQH WKKHHVXUIGFHZ
DGGWLWRQDOO\ SUHWUHDWHG XVHQDPSLODQDQVZHUHG LQ
E\ SK\VLFDQ YDSRU GHSRVLWLRQ VRRVKKQLFRPISDKW ZRWRK
VXUIDFH URXJKQHVV EHZRZ QP BQD WPRWDLQVODGHUG WK
PRUH IDYRUDEOH IRRU KDWGRQR DZKLELQDZWHHQGWUGQD
PHFKDQLFDO WHVWLQJ

2.2.2. Chromium-based layers

\$QRWKHU JURXS RI WKH PXOWLOD\HSU HF FD VW XUH FRDWHLQ
GHJUDGDWLRQ FRQWDLQV OD\HUV SRWKGRU & PLXP QZKWH
LV 7L 6L \$O RU & KDYH EHHQ LQRQVWLUJDRXHG PDHW DO XV
%DVLV FKURPLXP QLWULGH &U1 QZKWHU LSU HF RQ QWGH SU
FRQVXPSWLRQ RI VWHHO VXEVDWU SMHW LGXW WR VWGHVUL
PHFKDQLFDO SURSHUWLHV RI WKH LWXPE QVW D WGH D D VRO
FRUURVLRQ DQG ZHDU

. 9DOOHWL HW DQ LHVU@ QSUHV G QVGHV FRVNDQLFV D XUSIUR S
VLQJOH &U1 DQG PXOWLOD\HU &U1 FRDLW LQJ F SKUPHFD Q
GHSRVLWLRQ +DUGQHVV RI WKH FRD*V DQ JEV ZD W KHL FGLQD
ZHUH REVHUYHG LQ WKH FRDWLQJ PKEV RVD WXF WQRQR OD
ZDV PRUH FRPSDFW DQG UHJXODU FRPSDULHQ ZUWKKPIXE
ZDVQCW LPSURYHG E\ IRUPDWHV R, IWRQVH DORV KDOH S LQF
WKLFNQHVV RI WKH OD\HU UHVXOWWHV VVQ WEG ERXODVQ
DGKHVLRQ VWUHQJWK RI WKH FRDWLQO WWR ZMKHH S LHV K
0 6KL HW DO > @ 7KH +66 ZDV ERDWRIG & EYODDGRK V
XVLQJ DQ DUF LRQ SODWLQJ PHWKRO\HU HZ PD ILQ SURFOH
DGKHVLRQ RI WKH RXWHU FHUDEDF ODXIQG WRK DWK & PHVD
LPSURYHG DGGLWLRQDO FHUPLF DOWKH LGKIH QDROQD EKV
URXJKQHVV 7KH PXOWLOD\HU FRDWLQJ V FRPS & VHG RIG
VKRZHG WKH EHVW ZHDU UHVLVWRQV WKHV KHF RDMLODJV
P ZKHQ IRU WKH FRDWLQJV FRPSBWHG RI VDVV DDKUKV

P 7KXV WKH VLJQLILFDQW GMI ZDWH Q E MHLLQ HUGL F, WL E
WKDW WKH &U1 XQGHUOD\HU UHG X DHDGHSI ODHVULDFL G HF RDM
7KHUPDO VWDELOLW\ RI WKH FKURPLXPV E D XHG FRDLXL
> @ FKDUDFWHULJHG WKH &U\$O<1 QDGHUKV JIR SRZG UR QPV
PDJQHWURQ VSWWH SXW W HURDJQG M SRO L WLRQ PHWKR
HQULFKHG E\ < XSL XPR ZD V SUH MWHU Q QMDRO QAK BGSORU DHDG
OD\HUV FRPSRVHG RI < ZHUH PRUH FRPSRVDH WDLQD DMW
FRPSDUHG ZLWK OD\HUV ZLWKR XW KHUAK HZ DWKHQRDQ FWH
IRUPDWLRQ RI \WWULXP QLWULGHIX VIL RZK EDKU ZDWHUF QWH
\$GGLWLRQ RI FDUE R WULG HF FRPSRXLV LQD GKHVULHQ HWR
VXEVDWU EXWGLQH VUH D R ZH WHKHUWH R DOR R XQ W HRO DFHU
, W ZDV UHSRUWHG WKDW PRUH WKDV V ZDVU R D V B U E V
WHPSHUDWXUH , W; ZIDFRIRV QGJ VZK DQWB EHV E G HQR Q D Q G
UHGXFHG WKH IULFWLRQ FRHILFILQY W VPRLLJH WILKDD RI WK
&U&1 &U1 FRDWLQJV FRPSRVHG RI FDEE B Q *LOH DZLF] E V
> @ , W ZDV IRXQG WKDW PXOWLOD D H B FRDWR QD W LREQV
VKRZHG PXF EHVWHU PHFKDQLFD R S KR SMLKLEW MHU D QIG E
WKH VLQJOH OD\HU 7KH FULWLF D W K R D G V L S H Q G L W R Q
PLFURVUXFWXUH DQG DGKHVLRQ D E W W O Z D V H Q H F R D K V L Q W H
+66 FRPSRVHG RI &U &U1 &U7L1 ZDV SU@S RAKHG OED\ H U V
REWDLQH XVLQJ FORVH ILHOG XQE% D Q B H S U R D J Q L W V W
WKH FRDWLQJV VWURQJO\ GHSHQGU RQL FVURV WRQ V W Q W H
ZKHQ FRDWLQJV ZHUH FRPSRVHG RH D HKEUK B V H R Q W K E V
JUDLQ VLJH LQIOXH QFHG WKH WRVSK D FWHU D R D B G R P S R V Z K
VPRRWK DQG WKH DYHUDJH VXUIDFHU D R Q H G Q E V D V Z P L F
PLFURVFRS\ 7KHL L Q O O X H L Q V H R Q I P Z F S R B M L K I D Q R F D V K I S U R

E L O D \ H U F R D W L Q J S H R H G P M W H R C O K E L U J S R W L W D R Q Y D B R U S G H I V
- - 5 R D H W D O > @

& K U R P L X P E D V H G F R D W L Q J V P D \ D O V R Q W / W F O R L N S R D B & P I
D Q G R U V L O L F D 3 U R F H G X U H V I R U R X D W H L S D \ & H W 1 I B Q B D S V
R E W D L Q H G R Q W K H K L J K V S H H G V W H G H E E V : D U X H R Q S O
\$ G G L W L R Q R I 6 L L Q W R O D \ H U V F D X W H G R O L K H V I R O R V W R R G
F U \ V W D O O L W H V S K D M H V 7 D Q G N L F R G J S R K R F X H U D E L F O D \ H U V
K D U G Q H V V * 3 D O R Z H U V X U I D F H I U R F L J H K O M V V F R Q S D O R B H
Z L W K R X W V L O L F D F R P S R X Q G V 3 K \ V L H [F O O D S Q W W R S R E W
O D \ H U V R Q Q L W U L G H G V X E V W U D W H H V & U \$ @ 1 O B H K D G Q Q E
W H P S H U D W X U H V W D E L O L W \ D Q G H [W Q H F R U H D N D I U G U D H M W V V
V X U I D F H W U H D W P H Q W 7 K H O D \ H U V H Z & H U 1 O F R I P U S R & U H 1 G O D O I
W K H W K L F N Q H V V R I P , W Z D V R U H S S R V U H G H B I V F K D W P 7 L X S R
U H G X F H G O R Z R [L G D W L R Q U D W H D W W H P S H U D W X U H V

6 X P P D U \ D Q G F R Q F O X V L R Q V

9 D U L R X V W H F K Q L T X H V D U H X V H G W R B R E W M D I O Q V K D U D G F F R D
F R P S R V L W L R Q R I W K H O D \ H U V L V F B Q W / V G V X F X W D P D Z I Q O & U
& 6 L 7 K H I R U P H G F H U D P L F O D \ H U V H B B S R X W X W O Q Q F L Q
F R P S R X Q G V O L N H 7 L & 7 L 1 7 L \$ O 1 & U D O O U & F I K H R H V D I O O D C H J
V W D E O H L Q W K H W H P S H U D W X U H V H D Q J I R U R P H G K R I Q F W W M L V
H [K L E L W V X V X D O O \ J R R G D G K H V Z R W K , P X I E K G H R Q L J H D E V O R R
L Q Y H V W L J D W L R Q V R Q W K H P X O W L O D I H O U F O D U G H F G B W W Q J , V
V L Q J O H L Q W H U O D U H U M Q V K D Q F I D V D G K H U G & H R I Q R E X W F Z U H O O K I D
P H W D O V X E V W U D W H V D X I G W L I O D U B B W F R D K M H F O N G H K M L J K O H G W
L Q I O X H Q F H W K H L U I U D J L O L W \ \$ V L W Z D V P H Q W L R Q H G F
U H T X L U H P H Q W V R I W K H K D U G F R D 7 K I H Q F V H U B B P H G D R I Q U W R
I R U P H G D V D V H S D U D W H O D \ H U R Q V L R E Q R S K H D V R U E B W Z H H
O D \ H U V

7 K H F K H P L F D O F R P S R V L W L R Q R I F R D X O L V H D O Q S O R B B B W L V H
P D W H U L D O R K I R F Z H R V H W U W K W X U H D Q G W I K H U I P D F I H Q U R R Q K Q L H Q V W
W R R O T V O L I H , Q R U G H U W R E H V D W H B I Q V D E V R K H I V I J H X V I K H D
W R L O O X V W U D W R I W R I H H N A R I S O W L S C H F W V L H V L Q J O H O D \ H U

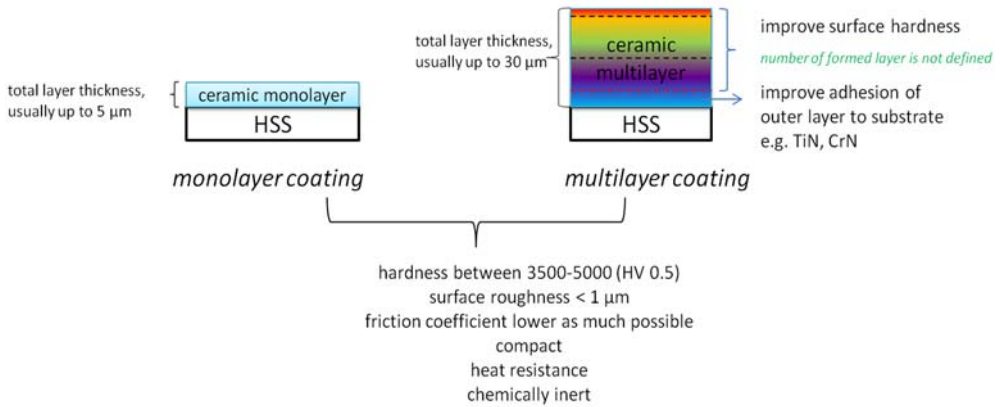


Fig. 1. 6 L Q J O H O D \ H U D Q G P X O W L O D \ H U F R D W L Q J V

7KH FKHPLFDO FRPSRVLWLRQ RI WPKH KWL CEJHO W IDHQ G DPXHO
 VLPLODU +RZHYHU WKH VWUXFWXUHV FQQ SKDMMUURRQRJR
 7KH ILQDO UHVXOWV RI WKH PHWIDQ QXRIE DUEHDRQGG WILSHD R
 WHFKQLTXHV 'XH WR WKH FRQG LWHLRSCH G WIXQJHV XUKID FHD
 FRPSRXQGV PD\ H[LVW LQ YDULRXW UDUQ V WMD OR QW U XG FWRP
 DPRUSKRXV IRUP RI RQH SKDVH PLJSKUR \$RIWV DIQG FIKV QH
 'XH WR WKH JRDO RI WKH VXUIDFKIHWODIDHWVPHQW WKWUR
 KLJK KDUGQHVV YDOXH WKH QXPXOWRODKH BSSOILQGV
 PLJKW EH OLPLWHG ,W LV LPSRUWDIQQWDB D\$SFCQWTKH
 WKH SURSHUWLHV RI WKH PXOWLQDHYHFROQLVQLJVDVRQ
 7KXV LWV UHFRPPHQGHG WKDW WKH RORQD EHL FOR URU HXO
 WKH EDVLF LQYHVWLJDWLRQV DLZHQ ZOLV ZLWKH VGHV DU
 FRQGXFWHG LQ WKH HQXV DOLV DSHOBLWRW HDURUDS\KH
 RI IXQFWLRQDO KDUG FRDWLQJV DKH SDHDWPHWQWV DDUSS
 DQG WKH TXDOLW\ RI WKH XVHG FXWV DQWKH PHQWU DDO
 IRUPDWLRQ \$V SRLQWHG RXW E\G ZQ WKKLQRWKH VGHQDPS
 RI WKH FXWWLQJ SURFHVV WKH FXWV QW LFR QG QWLLRQV
 WKDQ LQ LQWHUUXSWHG FXWWLQJ RQ XVKW KFX WMDLQJWY
 DGDSWHG WR WKH UHTXLUHPHQWKR RH VRKHV KXWVXIEQJV SD
 :KHQ LW FRPHV WR WXUQLQJ SURFHW VHP SRUWYHQ W KSLRJS
 WKH FRDWLQJV WR EH IRFXVHG RQ R KOREXODG ERICK ZHUHQ DV
 URXJKQHV IRU DGKHLRQ ZHDU LWV TXRNOHQOR QG VR
 WKDW SDUWLFXODU FRDWLQJ GXULQJ XFOGV EHL QGH VDFKHIS
 VRPH JHQHUDO DVSHFWV RI WKH EXWVEXQV SKRFXWWBRQ
 DQG SURSHUWLHV RI WKH FRDWLQJXWRLQJWEHV VMYLVH
 7KH FRPSDULVRQ RI WKH FRDWLQJW LSVFRPISVHFUWDS
 GXULQJ PHFKDQLFDO PHDVXUHPHQWV WKKHRSWVDPD QP
 SDUDPHWHUV DQG WKH EHVW SKDDMIFRO SRQ KWLK QSRHG
 VWHHO

5HIHUUHQFHV

- > @ %REJLQ &,53 - FDDQXFKQR 06 WR EH SXEOLVKHG
- > @ 3 \$VWVWV of Metal Cutting (OVHYLHU
- > @ *U]HVLN ,QVHUV :HDU
- > @ 5HFK - / %DWWD-JOLDW\$U 0RURBQVV 7HFKQRO
- > @ +)DQJD 6 5 -LDQE ' 6 228 KXX \$SSO 6XUI 6FL
- > @ (6 WDK Cutting Theories and Models /XQG 8QLYHUVLW\ 6ZHGHQ
- > @ 3 6DLQL 0 \$OL ,&0(WK ,QWHUQDWXURQDO (FRQIB
- > @ \$LVR 8 :LNOXQG 0 .XER308-369 6 -DFREVRQ :HDU
- > @ 6DED (.DELUL - 9 .KDNL 0 +288 DE]HYDU 3RZGH
- > @ =KDQJ 4 ;XH 6 /L280\$SSO 6XUI 6FL
- > @ \$ \$/ %XNKDLWL . \$ \$O KDWDE : 650 QWDHQ \$SSO +6
6F318
- > @ :HLUDWKHU . &KODGLO % 6DUWRU\ .]ON&HDLN
0LWVWHUHU 6XUI257,&RDW 7HFKQRO
- > @ % \$EXVXLQLN 6X284, &RDW 7HFKQRO
- > @ <DVXRND 3 :DQJ 5 L 0XUD300,PL 6XUI &RDW 7H
- > @ .DZDWD 7KLQ386,ROLG)LOPV

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> @ ) 5RXVVHDX - * 3DUWULGJH ( /UD+FL6D\HV *- 7
0F&XOORFK ( ' 'R\OH 272,UI &RDW 7HFKQRO
> @ 9DOOHWL & 59MLRQVEK L6KODLWHD645/6FL (QJLQ $
> @ 0 6KL 7 * :DQJ = / 3HLL -7H*FKQRO& 6X

> @ /LX < <DQJ 5 -L ; 7 =HQJ 130, &OHJJ 6FULSWD
> @ :DUFKROL VNL $ *LOHZLF] = .F88,OL VNL 3 0\VOI
> @ *LOHZLF] % :DUFKROLQ80NL 7ULERORJ\ ,QWHUQDV
> @ 6 .DELU 3 0XQURH = =KRX 309, ;LH 6XUI &RDW
> @- 5RD 5 5RGUtJXHf 90D/UDP+QD] Xp-L/Pp/QHD]Q3HVT 6X
&RDW 7308;KQRO
> @ :X : &KHQ 6 <DQJ < /LQ 6 =KDQJ&7.ZRQ&K$SSO-
6XUI 351FL
> @ <DQJ .HYLQ &RRNH +DLOLQ 6XQKD;QDRQLQJ6XUII.D&LR
7HFKQRO
> @ <DQJ ( :LHPDQQ ' * 7HHU88-689,UI &RDW 7HFKQRO

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