DEVELOPMENT OF NEW TECHNIQUES FOR IMPREGNATED DIAMOND CORING BIT WEAR MEASUREMENT IN CONVENTIONAL ROTARY DRILLING AND VIBRATION ASSISTED ROTARY DRILLING

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Development of New Techniques for Impregnated Diamond Coring Bit Wear Measurement in Conventional Rotary Drilling and Vibration Assisted Rotary Drilling

predicting wear rates are the bit the bit operating parameters and theeharacteristicsof the penetrated rock. This is a study of bit wear and a report on techniquesde\'e1operl and used to investigate bit wear. Two types of material were drilled with impregnated diamond core bits using a fully instrumented laboratory drillingrigal one rotational speed and over a range of weights on bil under a conventional rotarydrilling

Replicasofcutling segments on impregnated coring bits were made to record the status of the bits after drilling. Wear (weight loss and height loss) of each bit were

replicaswilh opticallllicroscopes. The wearalllountafter each drilling incrcascdwilh an increase in weight on bit. Comparing the wear amount in conventionaldrillingwith that in vibration assisted rotary drilling, the vibration assistcd drilling produced more cutting I001wear than the conventional rotary drilling under thC5allle weight on bit

Gratitude goes to faculty of engineering and graduate student office for their financial

Thankfulness is senl to all my friends al Memorial University for the help and happiness they broughl tome. Thctime I spent with them will caveintomymemory

Figure 9 Schematic description of the four main wear mechanisms (25] ....

specifically, a linearrelatiollship is dcsircd. Usual1ythereisa WOB with a maximum

cancel oul lhegains in efficiency. Significant savings could be achicvedbycffcctivc drillingoperationscould definitely reduce total drilling cost. Thevibrationassisted drillinghasalargerpenetrationratc, lowcrWOB,and faster tool wear rate.\Vearis

WOB, rotary speed, torque). and rock **type.** There are varieties of bit wear

Depending upon the economic consideration, a bit should be worn in an appropriate **rate** on both the matrix and the diamond particles. Thctheorcllcal analysis of the wcar process and wear mode is reviewed here. Howcvcr, previous studies were donc,mdc, 'hcco;",vcn'i,mal rolary drillingconditions. lnthis report, two new coring bits wcre used for wear mcasurcmcnl under both cOllvcntionalrotarydrillingandvibration assistedrotarydrillingconditions.Dueto **some** limitations of the drill rig and lack of the rock specimens, there are many challcngcsin this kind of experimental study. Thc work reported here isanearly phaseofthe VARDprojectusinga simplelaboratory drillrig, described inthe next chapter, involving a number of exploratory tests, mostly with small drill depths and with only one rock sample drilled under cach drilling condition. Thus, the amount of wear is small. The main targctofthe work reported here is try to find a feasihle assislcddrilling.Ouetothelimitednumbcrofhardrockspccimens.onlyone

vi bration assisled drilling tests were done by olhers. varyi ng the vibrationamplitude

Thefollowingchaptersaredescriptionsoflhedevelopmentandtestingof techniqucs for recording the state of the bit surface and measuring the small amount of wear involved, mostly in the dri lling ofconcretc samples. Once lhesc techniques \ierctested, lhey were used during a set of experim ents in which the hard rock was

Chapter 2: Literature Review

2.1: General Dcscriplion of DrillingTcchnology

machincsarealsollsed inclltting shafts. Smallcrbore drilling is perfonned in

inciudingcxtraclingrockcores.Rolarydrillinghasbeenacommonlcchnologyin

2.2: Rotary Percussion Drilling

Percussion added to rotary drilling increases pcnctration rate (ROP) andlowers the weight on bit (WOB) which is needed, and is therefore more economical ROlary-Percllssivedrilling has gained more and moreintcrcst in oil and gasinduslries

provides 7.3 timcs faster penetration at most than conventiOllal rOlary mclhodand has 2.3 times advantage in ROP at the best operational conditions, and lesscontacttime between bit and rock,that leads 10 longer bit life, less hole deviation, and generates larger cuttings. Unfortunately, there arc no practical simulation tools available 10 hclpdcsignand optimizedrilling operations. These lead locostandreliabilily concems. limitingthewide-spreadapplication ofrolary-pcrcussion by industry [3-8] Main advantages and disadvantages are listed as [8-10]

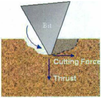
rock isgeneratcdbya pneumatic or hydraulic rock drill. A pressureis builtup, which,

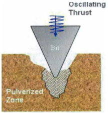
and the kineti c energy of the piston isconvertcd into a stress wavetraveling through

the drill string to the hole bottom. In order to obtain the best drillingeconomY, the

lcadsto two major rcaetion forces in therock·bit **interacting region:** verticalthrust

thepcnctration and drilling action IheWOB should be high enough to keep cutlers in





According to the law of conservation of momentum, drill bits can producehigher

impact force in bit movement direction with higherspccd of impact andshortertime period ofconluci by accelerating the bit. In this type rocks will becrushed by impact force when impaci force is equal lorockcompressivestrcnglh. Thecrushed zone is longerthantheimpact zoneofdrillbit[II].lnrotarypercussivedrilling the rock is broken by repealed impacts and rolation imposes on lhe bultons a new point of impact cvcrylime. Thustherock isbrokcn and crushed and flushed out fromthehole by drilling fluid. A roturypercussiverock drill isin a very tough drilling condition [12]

c) Failureduetofatigue viaexcessivelension-eompressionslalein the rock

In summury, there are four fundamental stages in rock breakage in percussion mechanism. Firsl, thc bit penetrates the rock while the bit vibralcS and transferring impact 10 lhe rock. Second,theimpact istransferredcompletcly to the rock and space. Basedlontilesee,,"sideralions.JPL·sNDEAAleamandengineersfrom

Cybensonics, Ine.d"velop<:d a ne,vdevi,ce, lhe Ultrasonic/Sonic Driller/Corer(USDC)

and frequency, the drill tip loses contacl with thcwork piece periodically [13-1 7]

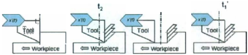
Fig. 2 illustrales the dynamics of the vibration assisled drillingprocess in machining and can be explained by lwo equ3tions in this example for vibration

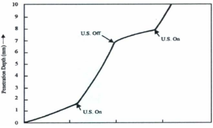
A is amplitude of vibration; roisanguJarfrequency, which is rclatcd to vibration frequencyfbyro=21lf;Visupfeedvelocity;X(t)andX'(t)areinstantaneous position

Part I of Fig 2 shows the start point of vibralion assisted machiningprocesst,in which vibration is superimposed on aconstanl rate oftool fecd. Al Ihispoinl. lhe tool ve!ocityX'(t) is greater than zero and begin to cut. Part 2 presents the criticaI point of positive direction of vibration, at this point, the motion ve!ocityofthe tool X'(t) equal

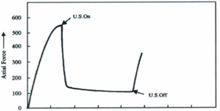
vclocity hasa reversedireclion andlhetooltcnds lomovefar awayfrom the work picce. The last part of Fig 2 indicates that thc velocity is inpositivedirectionagain

means a new cycle starts. The duration lime T ofeach cycle is equal to l/fandthe





gives an example of force reduction while drilling wilh a conSlanl drilling ralc (penetration rale). Olher paramelers are samc as lhose in previousexpcrimenl.Whcn



2.3 Fundamentals of Impregnated Diamond Coring Bit Wear

Rock drilling is an important opcralion in mining and pclrolcum induslries. The cffortslowards improvingdrillingcfficiencyareessential forreducing the costs. In lhe view oflhe heavy dependence on rock drilling in mining, any incrcasein efficiency, even if small, can lead 10 substantia] cost rcduclion [22]. Thcmain faclor that has a significant cffecton drilling performance or cfficicncy is thedrillbil.A common bil type in rock drilling is the imprcgnatcddiamond coringbit. The impregnatcddiamonddrill bit usually consists ofa stccl body mountcd with several impregnflcddiamondsegmentsul its cutting surface. Diamond particles are randomly distributcd inside the segments and are surrounded bya mctol malrix(Oftcn cobalt possibly with olher components) [23}. Duringtherockcultingoperations,themetal malrix is gradually wom away, exposing lhe fresh diamonds wilh sharp cutlingedges to do the actual cutting. The metal malrix musl hold and support the freshlyexposed in order to remove the worn diamond particles and continue to expose fresh diamonds

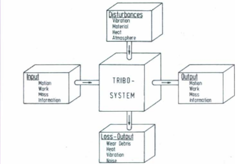
Thus. the performance and the life of impregnated diamond tools depend mainly on

Wear is not a property of materials, it is a process in a system [27]. Tribology is

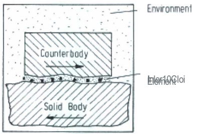
this matter, the tribologists suggest using a tribosystem (Fig. 5) that considers the

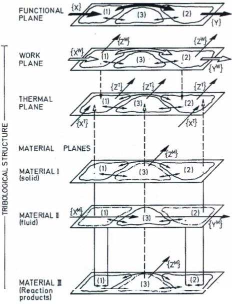
useful input and a useful output may be considered as the technical function of a tribosystem. Friction and wear results in undesirable outputs such as wear debris, heat, vibration and noise. Useful inputs and outputs may be classified in motion, work, materials or mass, and information. Structure of the system is determined by the elements, their properties and the interactions between them as shown in Fig. 6. The structure of a system is characterized by the elements or components of the system, their relevant properties and their interrelations. In simple cases, for example.

gives the tribo-process in the example. In Fig. 7, {X} and {Y} are the inputs and



Tribosystem





relative sliding motion at thccontaci surface. Wear can bcgovemedby (a)lhetype and propertiesof lhe interacting matcrials, (b) lhc drilling parameters, and (c) the type ofmaner.Independcnllyofanyspecial wcar mode, lhctypeofmcchanicalconlactis vcryimportan1forali wear losses.Consideringfirslno liquidprescnt, lwomajortypes

Considering asperilies as individual contaclspots, theclasticstrainsandslressesalthe

value,lheelasticlimil.aplasticzonedevelopswhichissurTOundedby elastically defonned material. Ahhough there are only lwo significant types of surface contact, many lypes of wear can be induccd by these lwocontacts (e.g., abrasive, adhesive. erosivc,fretling,andcorrosivewearand surfaccfatigue).Anuidpresenl in the system will also lake part in wear processes. There is morc lhan onc way to labcl and

involvc..'dsliding,rolling,oscillation,impacl.anderosion. ln erosion,OuidorgasOow

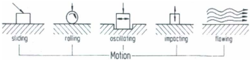
also be described according to keyaspcci of the way wear particles arefonned,such as (a) abrasion, (b) adhesion, (c) surface faligue, and (d)chemical reaclions. One or

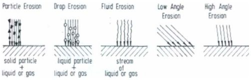
relative molion (sliding, rolling. etc.). Corresponding motions causing lhe difTerent type of wear are illustraled in Fig. 8. Sliding motion can induce entire abrasive and by impacting. Fretlingwear is caused byoscillalingmolion, Iherefore it can also be

infrequentwcartype,corrosivewear,iscausedbychemicalreaction.According to

we3rlypcs.fourm3joTtypcsofwearmechanismsaresummarized

explanation of wear mechanisms is illustTaled in Fig. 9. Table I summarized all the





nbocmicol
Reaction

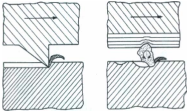
Impregnalcd diamond coringbils arc widely used in rock drilling, and therehave

processes arc the 2-body and 3-bodyabrasion (Fig. 10) which is caused by the

diamonds [26]. Previous studies [29] indicalethal there is a critical tcmpcraturefor

each material above which its properties may change. The first function o fwaterflow

Type of wear	Type of contact	Motion	Wear mechanism
Abrasive	Elastic/plastic	Sliding	Abrasion
Adhesive	Elastic/plastic	Sliding	Adhesion
Erosive	Elastic/plastic	Impact/sliding	Abrasion
Fretting	Elastic/plastic	Oscillating	Adhesion Abrasion
Fatigue	Elastic/plastic	Rolling	Fatigue
Corrosive	Electrolytic	electrochemical	Chemical reaction



2.4: Experimenlal Investigation oflmpregnaledDiamond Coring Bit

coring bit matrix and its cutting diamond particlcs. ASl1lcntioned abovcthe overall

pcrfonnance of any drill bit can be affcctcd by numerous of factors whichincludc

operating parameters of the bit, fonnation propcrtics, bit design and type, wear

capacily of the drilling machine, time, climalc and opcralororcrcwefficiency

arc operating paramctcrs of the drill bits and penctrated rock properties[30].Prcviolls

a) Calculating the weight loss between two distances cored. which iSTaintcdwith large errors becausc lhe weight loss can come from the noncoring bit [3 1]

severalprofilesareobtainedby taking themeasurementsacrosseach segmenlof

difference in average profile shape measurcd before and after a distance cored

positions on thebil surface are taken [32, 33]. This method can beapplicdfor

c) Mcasuring thc weighl loss llsing the balancc. Tllismcthod has a rclative high precision ofO.1 g. However,themethodcanhavc limitations,asill our laboratory ducto the insufficientcieaninganddryingofbilbodY, and surface

d) Measuring the volume change of bil by liquiddisplacemcnt tneasurements, this

fine point which was clamped in a vcrtical plane and placed on a smooth level

g) Recording thc drilling opcralion paramelcrs and cxperimenlal resuhs, then convert to wear vector by stalistical and mathematical models [34,35]

theworkrcportedheretosimulalctherealisticdrillingcondilionsusingimpregnaled diamond coring bits undereithcr sct thrusl or a sci rale ofadvance [36]. In their study. they used a modified pillar drill with a lighl-alloywheel fillcd to the manual feed

ralcofpenetfation **when** required. The rock spccimen wasclampcd insidethesplash

coolinglhc bil andflushingthccuttingsenteredlhehollowdrill slringthroughawalcr

widc walcnyayssylllll clrically placed.Anatlachedrigidbeamimpingcd on a load cell to measure lhc generated torquc. The gross powerconsumcd was measuredby a recording wattmeter and the values were corrected for power losses inlhclllachine

Their tests were done in a hard homogencous rock. Unused bits were conditioned by drilling aboul 0.5 m in abrasive sandstone al 5 MPabil pressure in order l0 rcmove thccoatingandlhefirstlayer ofdiamondsand ensurcarandom orienlationof the exposcddiamonds. Lincarbit wear,suchastolallenglhchangcand out and inner diametcrschange, was measured on a special micromcterjig, the rcsu!t was nonnalizcdtolmdrillingdistanceaswellas thebitmass lossrecords. The extent

with a stereo optical microscope using the dcfinitions ofwearcatcgoricsinTable2

Worn diamond displaying well-developed wear flats
Worn diamond microfractured inlo multiple sharp points
Hole in the matrix representing recent loss of diamond
Diamond broken ofT flush with the matrix

Details of diamond particlc wear featurcs were studied by scanning electron microscopy (SEM). The particle size distribution of the drilling detritus was detennincdbysenlingthesizefTactiongreaterthanO.063mmin asemi-automatic hydraulic setting tube. The size of fraction «0.063 llllll)was recorded as a percentage by mass of the recovered dctritus. The detritus were studied by SEM to evaluate the

summarized in Table 3. Rcproducibility tcsts werealsoconductcd to estimate the

Diamonds	SDA I00,20-80U.S. mesh, usually in step of I0 (e.g.30/40 or *40/50)*, concentration 30
Flushing	Tapwater, ahout 350 I/min, 200 KPa
Rotaryspecd	Nominally 3500 rev/min (3.5 m/scc)
Bit pressures	0.5-13MPa
Advanceperrevolution	O.OII.O.lmmlrev

increased linearly with the increasing of bit pressurcuntil the stallingpoinloflhedrill

The penetration **rate** increased until 0.1 mm/rcv and then slabilized wilhincreasingbit **pressure** under set thrust mode. The optimum bit pressure was 5 MPa under both

bydiamondsizc. Bctween5MPaand IOMPaandabo\'e, apeakROPwasobtained at apaniculardiamondsize.Thehigherlhcpressurcthesmallerthediamondsize producinglhepeak ROP. The peak ROP increased with increasing bil pressure.Bil

independent of diamond size at 5 MPa. Al 7.5 MPaand 10 MPa, bit wear rate was about thesameatthesetwopressuresbutincrcasedwithincrcasingdiamond size. The

diamond wear, macrofracture and pUII·OUIS, look thcprcdominalcd portion ofwear Thus, lhc sequcnccofweardc\'e1opmcntofindividual diamondswas ·I) unwom;2)

Finally, the lracks on the punch-through discs of rock were the same in **appearance** for all drilling conditions. Ahhough no clear tracks were oblained.lhc

Irackof singlediamondcouldalsoberecognizedbylhe rcmnanlsofstriatcdannular rings of reground and sinlcred rock flour adhering to the track. Thedrillingdetritus consisledmosllyofangularfragmentsofcleavedcrystalsanddetachedsinteredflakes ofrock flour. Optical microscopy ofsections cut through lhc rock beneath thebit was

Tian and Tian [24] and ErsoyandWallcr[28] investigatcdtheseparameters. In

in\'cstigations were promoted. Tian and Tian evalualed the friction andwearof diamond against rock in expcriments using a single diamond cuner, as well as an impregnated diamond bit wilh atungslen carbide malrix in a soft binder. lnbothcascs

coefficicnloffrictionwasstronglydependcdon thecharaclcristicsofrockfraclureat contactingsurfacc. Itrangcsfrom O.035toO.065ifdiamondsslidcovcrlherock surface without significant local bulk fracture of the rock. Otherwisc, the cocfficient

lhcrocktypestested. lmpregnatcddiamondmicrobitdrillingtestswercconductedto observethc wear processes of both diamond and mClal matrix at variousdrilling

parameter influcncing lhc wear behavior of impregnatcd diamond bils.Thesludy

on their structure and material properties but also on the operational paramelersof rock drilling. Wear of the matrix at moderate rate ofpcnctration isdcscribedas combination of micro ploughing and erosion resulting in excessivc Wear. Brittle

propagation undernonnal drilling conditions. Under high langentialforce,macro

ErsoyandWaller[45]invcstigatedthewearofthrCClypes ofbilS. tWO lypes Of PDC bils (pin and hybrid) and an impregnatcd diamond bil on fivctypesrock. Their observations on lhe type of wear of the bils are similar 10 Millcrand Ball. 0 consistent correlation independent of the lYJlC ofrock was foundbetwccn rateofbil wcightlossanduniaxialcompressiveslrenglh(UCS).ltiscXpeclcdlhalhigher uniaxial comprcssive slrength giveshighcrwcarrale. Thcy found lhat bit weight loss rate depends nonlinearly on rock grain size, grain shapcand grain tcxture:minimum at a particular value ofeach ofthescparamelers. Weight loss ratcincreasedwith silica content, at]casluptoabout70%silica,ata ralewhichdcpcndcdOil the type ofrock No single rock propcrties exists that correlate with lhewenrof bits.Some significant factoTSwcrcidcntified includingrock strength efTecl, tcxturalefTecls, hardncss cffect,

resistanceofvariousmincrals lhroughtheabilityofa hardermatcrialto scratch a index',dynamicimpact abrasive index' (DIAl) [42] and F·abrasivityfactor [43]

loadof7 Kg, this pin is pulled OVCTone centimetCT of fresh fracture surface of rack

Thcdiametcrofresuhingabraded flat on the steclpoinl, measured in 1/10 mm.

highcr wearrate ofthcbits is. The wear rate of bits is less sensitive to DIAl than to

the Ccrchar index' [42]. DClailsofSchimazek's F-abrasivityfactor can be found in

ErsoyandWallcr[44] and Ersoy[45]. According 10 Waller and Ersoy, lhcmaintrend

AnOlherex,pcrimcnl wasconducled by Ersoy and Waller [47] to invcstigatcthe

influence of drilling detritus on bit wcar by using the same bits and rocksundcrthc

same drilling condition. The particle sizeoflhe drillingdetritus incrcascd with

increasingWOB,whichalso incrcasedthewearralcsofthebils.Also, lhc portion of

of275 kg, the specific cncrgyof210 Mpa was a minimull1 value, that produceda

thisvalue, thcrcwasa dramaticincreasingofspecific cncrgyandmcan size of drilling

detritus. with a rapid incrcase in weight and hcight losscs ofthc bit. Accordinglo and the original rock grain size because they statc ofrcgrinding andtherock

Erroy and Waller [48] used both measurementsofchangcs in height to a

of the relationship between the bit wear and rock propcrtics, but it is vcrydifficultto simulatc inbothfieldproductionandlaboratorybecausc therotary speedofdrill string is too high. onnally therotaryspeedofadrill stringisnomorcthan 200 rpm in field production. Furthcnnore, they just quantized the wear and ignoredthcprofile change of the bit which is very important to bit wearevalualion

of 0.035 mm perpoinl. From fourhundredseparatcradial scans, an averageprofilc was computed. A measurement of this type pemlits the measurement of volume changes within ±4 mm^3

Another significant faclorwhieh canafTect the wear rate of the impregnated diamond coring bit is the temperature that is generated at the bit rockinterface during the drilling process. Ersoyand Waller estimated the possible tcmpcrature atthe tip of

them were dealing with PDCbits. Theeoneem is that diamond can graphitizeat friction in cutting process is relatively high, and the drilling detritus could be highly

Rao *et al* [22] built another test using drilling fluid, water with and without an

penetration rate enhanced and the torque generated at interface reduced by using the

drilling fluid. The severe wear caused by the high temperature generated by the

level, since the stresses on the diamond grits will be less because of smaller

with the rock will be subjected to higher stresses, consequently they are more liable to

micro fracturing. Drilling at lower thrust levels at higher rpm will result in cavity

Chapter 3: Experimental Investigation

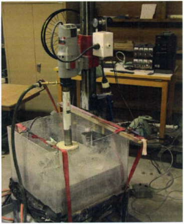
3.1 Deseription ofDrillingSystem

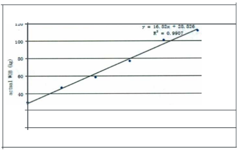
ThcexpcrimenlaldrillrigsyslemisshowninFigl1.Thelaboraloryscale experimental faci lity of the VARD project is built up from a Mi lwaukee 4079 electrical powercd coring drill rig. The rig has two rotary speeds (300 and 600 RPM)

allhesidcinstcadoflhe original handlebaraSlhcsoUfceofconslant weight on bit (WOB). A flow meter is mounted under the driving mOlor which can measurethe flow rate and the drilling fluid pressure. Following a study by a colleague, the flD\\' ratcof3 gal/min was chosen as it has lhc minimum cffeCI Oil thcpcnetration ratc. The impregnalcddiamond coring bit is driven by the motor. An clcclfomechanicalaxial

specimen placed on a lllctal platc fixed on the shaker. The shaker is opcratcdundcra specific value offrcquency which is 60 Hz. The shakercontrollcrhas amplitude scnings markcdfromOt060byincremenlsof I0. Inthiswork, knobpositions I0, 30

hung weight thai can be applied on lhewheel is 7 kg. therefore, all bit weightsused in this study were !owerthan or equal I07 kg. Several parameters were rccordcd,suchas was investigated by another masler candidate (Heng Li)in lhcYARD group, with lhc





ThcdrillbilswcrcimpregnaleddiamondcoringbilsoblainedfromDiamond Systems Inc (Bramplon, Ontario), 2 inch Solid End Formula .400. There arc five segmcnls,lheinsidcandoutsidediamctersare45mmand 52mm respectively. The scgments arc separated by waterways, which are8mm decp, 4mm wide on the inside,

3.2 Test Specimen Preparation

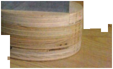
Thedrill specimcnswerc madefromQUIKRETEFast-scuingConcrcteMix o

grcaterthan2.63 mm were sieved out of the QUICKRETE concrete and the consistence as judged by thc technician. Six inch diameter, twelve inch high plastic cylinders were filled by the mixture from this one batch. After mixing. all the filling

minutcs.Thespecimenswereset aside for 30daysatroom tempcrnture.TheUniaxial Comprcssive Slrength (UCS) of specimen **was** about 40 MPa, which wastreatedto reprcsent a soft drilling material. All the drilling tests were pcrfonned on concretc

The hard rock specimen was collected from Bay Bullsbcach. St John·s. NL.

rock piece was cut into a rectangular block which had thcdimcnsionsof8inchlength, 4 inch width,and4 inch height. A wooden plate, which wasa6 inch diametcr, 3 inch high cylinder witha4 x 4 x O.5 inch rectangular cratcr on thc top surface was madc for the rectangular hard rock block to sit in (Fig. 13). The whole sample was put into thcsamccylindcr used in concrcte sample preparation and thcempty placc was filled with the ready mix concrete. The test specimcn dimensions and weight were limited to the space available on the drilling rig, and the weight the shaker can support. Also, this study was in parallel with othcr studies of drilling perfonnance using thcsame cquipment.Basedonthisconsideration,thespecimenwascut intotwopans through themiddlc toprovidetwoidentical samplcs. lnordertokecpthctwopartsatthcsame weight. after taken off the wooden plate' **the** renlainicd empty space was filled with



3.3 Preliminary Data Processing and Conclusion

In the following all the preliminary tesls werewilh conerete sampl es. For each

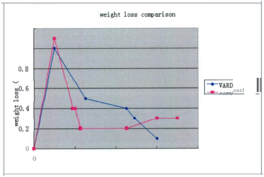
represented by several parameters. sueh as weight loss, height loss, and insidcand oUlsidcdiamctersehanges.Testswereperfonncdon conerctesamplesat scveralhung weightsinconvcntionaldrilling.Theteslswercdoneinthesequenceinwhichthey

amplitudes with several weighlswereapplicdanddimensionsrecordcdaficreach run

1. Weight loss measurement. After each run, the bit was washed and dried,

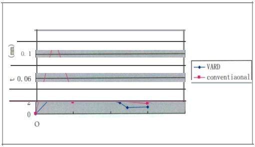
comparison of weighI loss underbOlh drillingcondilions. The weightof the bit was measured by a digital balance with the rcsolution of 0. 1 g(Fig

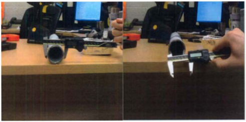
vibration assisted rotary drilling (VARD) witheonventional drilling (withoutvibration), fasterwearrateofdrillbilwerefoundinVARDas illustratedinfigurcl5. Firstdatapoinlshowsadramatiewearrate.whieh isductolhcpaintlossoflhesidewall,soitcannotprcdiellherealbit wear. Comparing two adjacent data points on each curve,thediffercnee

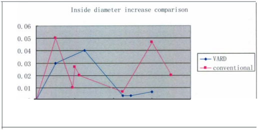


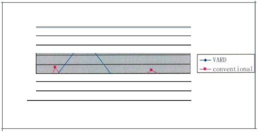
2. Height loss measuremenl.Theheighllossonlyhappcnsonthesegmelli S, so lhere is no necd to investigatc the height loss for entire bit. Adigilal caliperhaslhe resolutionofO.OlmmW3schosCIIIomeasurClhe heighl change oflhe bil. The gaps between every Iwo segmcllts which were named as waterways were markcd by numbers from 1 to5. After finishiog washing and drying, the bit waspulon a flat surface and the height of each walcrwaywas measurcd. The change in watcrwayheighl after each run of drilling can be used as lhe hcighl loss of the cuttcrs, in olher words, lhe

Fig. 16 and Fig. 17. There is no obvious increase in heighl loss on vibration assisled drilling compared 10 conventional drilling at lhis


(mm)
0. 1
0. 06
2
0
O
VARD
conventiaonal







lfwccomparc lhebil wear at samc weight on bil in Fig. 15 and Fig. 17, the

in Fig. 17, whcn the hung weight is 2.5 kg, values of height loss in both drilling

kg.bolh inside and outside diameters changes are much greater in VARDthanin changcarcshownin Fig. 20. Fig. 2 1 and Fig. 22. Thc points arc conncctcd in the sequence of the tests. In these figures. it wascasyto find that with

particularly height changes at high vibration amplitude, knobposition 50.

highcrvibralion amplitude causes morc bit wear, in olhcrword. if the vibration amplitude is 100 high, thc bit life would bcshortcncd. It is very important to control the vibration at an appropriatc!cvcl.AIJ Ihc rawdata

	Weight (g)		Average outsideDia	Average

	Weight (g)	Average segmentlellgth	Average outsideDia	

	Wcight (g)	**Average** scgmenllcngth (0101)	Avcragc oUlSidc Dia	Avcragc insidc Dia

	Wcight (g)	**Average** segmenllcngth (mOl)	**Average** outsidc Dia	

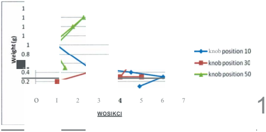
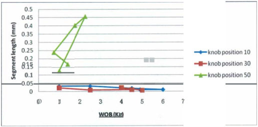
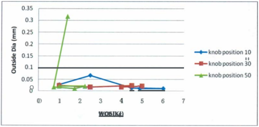
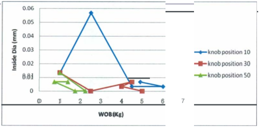


Figure 20 Weight loss amount at differenl vibration level





Outside Dia (mm)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0 1 2 3 4 5 6 7
WOB(Kg)
knob position 10
knob position 30
knob position 50



Inside Dia (mm)
0.06
0.05
0.04
0.03
0.02
0.01
0
0 1 2 3 4 5 6 7
WOB(Kg)
knob position 10
knob position 30
knob position 50

Mary, FL USA). For this the coring bit was placed on a flat bed and the location of a

3.4 Subsequent Work

changcswasloplaceindenlationsinto thedrill bil3s a rcfcrcncc, and to Illonilor the size and profile of indenlations as the bit wears. For examplc,asl**hebilwearsaxially.**

measurcthechangeindepthofthe indentation as radialwearoccurs, theconical

Two main types of indentations were used: conical and spherical. Theposilionof

center punch must bc uscd bccause the Rockwell hardnesstcstercan not be used to

locations where after visible wear occurs to get an idea of how the segment is wearing

To pUl the conical and spherical indenlalionsintothedrill bil.ahardnesslester waslhemainlyusedinstrumenl. For the conical indentations. the Rockwell C hardness tester tip was used wilh a 150 kg load in lhc position of interesttoproduce

usuallyapplicd with a 100 kg load. However, more weight was uscd to producea largerindentation.Whenmakingindentationsitisil1lportantloavoiddial1londsin lhe bit to avoid damaging the hardness lesling lips. However, it was not always possible to avoid dalllagc I0 coneofindcnlcr.Thercforeit isprobably bcllerto usc a ccnter punch. For places thai the hardness tester cannot fil. indentationscan bc placcd with a ccntcrpullch.The upperpartofFig.23isthchardnesstcsterlhatis used to put indentations intothcdrill bits. LowcrpartofFig. 23 showstwoindcnlers (thc left one

The procedures of measuring the dcpth of an indentation. thc diameterofan

watcr way faccs arc given as follows. After all thcindentalions are measured on one segmcnl, rcpcal the procedures on the others scgmcnls and record all the data

3.4.2l\1easuring the Depth of Spherical Illdcntalions Using the Reichert enough power was employed to assure an accurate measurement but not so

focus and the position of the fine focus knob was recorded when the edge of measuring small amounts of wear, wear that is no more than the depth of the

Tests were carried oul 10 find out Ihe accuracy and reproducibility of measurements of

An indentation procedure produces not only an indentation; italsodeformsthe material surrounding the indentation, raising the surface **above** itsoriginallcvel. In this test the microscope was focused on four perimcter locations. labeled A.B.C.and

O

perimeter1ocatiolls. labeled A'. B', C', and D'. each

timcsscparalclyollthcsameindentation.Beforeeach set ofmcasurcments thccoarsc focussctlingon the microscope was changed. so that each set of measuremenls is indcpendcnt ofthcothcrs. These ninefocus mcasurcments, providingeightdepth values,wererepcatcd three times. The following table shows the indenlationdepth

As expected. the indentation perimeter was raised about 17 micronsabovethe surface 0.5 mm away from the perimeter, a value both observers obtained.Thedeplh valucsobtaincd by observer I were, on average 4 microns greatcr than those by

ofeach reading from the average ofthc three depths referenced 10 aparticularmelhod

It would appcarthal this kind of measuremcnl, which involvcsfocusing in lum on

A WildM420binocuiar zoom microscopewasuscd for measuring the end and

magnification in the rangeofx3. 15 to x64. A spccial setup was needed toobtain an

mcans that the cdge of the bit. is not the same as lhecdge sccn on the microscope

slide was held againsl the end face of the bit, held in placcbyanelaslie band which

wasstrctched lhrough lhe insidcofthe bit and held in placebyawire. The cdge of the

and edgeoflhc glass slidcarcboth in focus and can be uscd asrefcrcnces to monitor

thewcar.Additionally, thecamerawasalso uscd herebecauscthe Wildmicroscope

that fiucd in to the Wild microscope. The best technique was to mcasurcoff of the

photographs. After applying the above setup (shown in the pictures below) the

followingprocedurcswcre usedtomeasure thcchange in axial wear

(1) The drill bit wassctup on thc Wild microscope as dcscribed in appendix A

(5) Distanccsbetween indcntationsand edges were measurcd **by** using the ruler

profile. Then use an analytical scale to weigh the paper. With wear, the

method would be to use edge detection software to determine the change in

and shrinkage. Each one ofthcse charactcristics can affcctthe finiShedproductand how it is prepared. Forlhis projectaharderrubber wasappropriate. To crcatc the positive replica. an cpoxy was used on the negalivc lo crcatc a hard, accurate, plaslic rcplica. Theepoxywas usedbccauseit hasaslowpourtimc. ishard whcnscl. does not rcquirc any safety cquipmcnt (such asa fumchood). iseasytouse.andproduces accuratcresults.Itisimportanttousethcepoxythatwoncsundcrthespecific

time, so thai timc is nol an issue when creating the positive. The majorbcnefitofthis

mixcd to producc Ihc epoxy. to leavc the specimen. Bclow is a photograph ofa finished replica and Ihe procedure for cre3ling a replica ofa drill bit is describcdin

The epoxy used 10 crcatc Ihe replica **is translucent** and is not a conducling malcrial. To study Ihe replicas in the scanning clcclron rnicroscope, and tornore casily sec thc rcplica on thc optical microscope. a coating is ncedcd 10 makc it opaque

conductivc and opaquc surface for the optical and scanning elcctron microscope

(I) If lhc rcplica is not conductive. the elcctrons fi rcd at the spccimen in Ihe SEM will only charge it, not reflect from the specimen. and no infomlation wiJIbe

(2) If the replica is not opaque **it** will be very difficult to make distinctions

In this project gold was used to coat lhe replie a because it is conductive, reflective, and relatively easy to work with. A small piece of **gold** is placed into a tungsten basket above the replica in a vacuum chamber. The gold melts onto the tungsten upon heating. Ihen evaporates as the tungsten is heated further. The evaporalcd gold atoms move freely in vacuum and bccause the replicas Were uncontaminated by grease or oil, the gold adhered to it (and all other surfaces} in a thin laycr. This ensures that the replica has a conductive and reflective surface. which

<listinguishonanoplicalmicroscopc.Thcinstruclions forlhcopcrationoflhecoater

3.5 Diamond Study and Observation

To thispoinl of the projcct themalrix component of lhc drill bit is all thal has

sludyingthediamonds. Before studyingthediamondsilisimportanlto lake note that all high magnification work on the Reichert microscopc must bc done using the replicas, to avoid scralchingand ruining the objective lenses

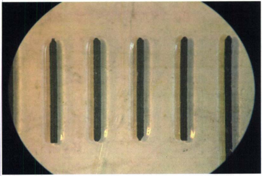
Onc difficulty would be locating each specific diamond bctwcen drill lesIS because of the small size and random dislribulion. By laking piclures at lower magnifications a 'mnp" canbcgcncralcdfor idcl1tifying individu<lldiamondlhenzooming in 10 them by using the phologmphs as a guidc. Another factor which may lead 10 difficulties is Ihatdiamonds may fall oul of the matrix during a drill tcSl. So il was important to idenlifya diamond, then work backwards chronologically by usinglhercplicates

3.6 Results of Subsequent Work

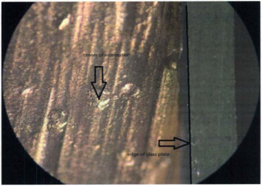
with a I kg hung weight, drilling 10 a a little than the depth of the raterways loalso cnsurethewalerwayswercsubmergedinthesubscquentruns.The

4		NV			Actual			Bill		V			Actual		
Plan increm. mm	Plan total mm	WOB	Date	Duration s	total depth mm	Increm. mm	ROP mm/s	Plan increm. mm	Plan total mm	WOB	Date	Duration s	total depth mm	Increm. mm	ROP mm/s
	8				9.8	9.8			88				88	8.8	
					19.6				816.0				17.6	8.8	
7	23.0														
7	311.0								7311.0				31.2		
7	37.0					81	0.1		7137.0			35.8			
7	44.0			87.8	50.2	7.0l	0.		7144.0			47.7	50.2	7.5	0.1
7	51.0			48.7	57.8	7.6l	0.1		7151.0			33.1	58.8	8.6	0
	58.0			42.7	65.3	7.5	0.1		758.0			1367	63.6	4.8	0
7	65.0		4	160.3	74.1	8.8	0.		765.0		4	96.6	74.1	10.5	0.11
7	no				83.6	9.5l	0.14		7172.0			34.5	81.5	6.4l	0.1

calibration picture. There were four indentations on each cuttingsegment, two of them were cl0sc l0 the leading cdge, and anothcr two were close to the trailingcdge The replica was mountcd to a plastic pipc which made the measurement easier to perfonn. A glassphuewasplaccdonthecdgeofthecultcr asa referenceplane, and Ihc picturcsofthc sides of the segments. including indentations were taken at both leading edge and trailing cdgc with the same magnification as the calibrationpicturc

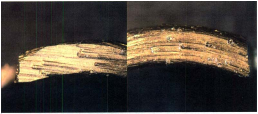


AS lllentioncdintheprevioussection, thcdistance bctwccn the centerof each



(part a). The grooves on the trailing edge are parallel to lheprofileofscgmentedge

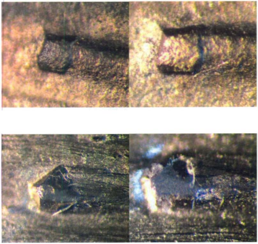
lhecur\'edgroo\'cprofilesonrhetrailing edge showed that moremalrixwear

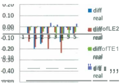


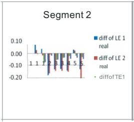
microscopewilh thc magnificationsettingof x64. In Fig. 29, thesame diamond particle is tracked. Part (a) is the diamond particleclose 10 lhe leadingedge; part (b) is the same diamond particle aftcr lhrcc drilling tcslS. Comparc part (a) with parl (b),

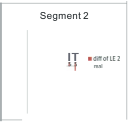
ocellrred oll lhe edgcoflhe diamondparticlc. Part (c) is a diamond particle close to lhc trailing cdgcon lhc same segment and part (d) is the samc diamondparlicleaftcr lhrcc drilling tests. Compared with part (c). which is undcr same siluation as part (a),

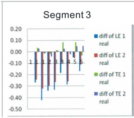
type of bit. Acomel lail is a ridge dircctly behind each protrudingdiamond, thewidth of the ridge tapering to zero. In addition, lherc is often a groovecurvingaroundthe diamonddirculy infront of it.Thisgrooveand thecomcttailaremostlikely

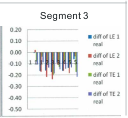


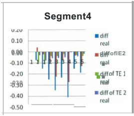
Segment 1	Segment 1
	

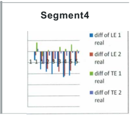

Segment 2
0.10
0.00
-0.10
-0.20
diff of LE 1 real
diff of LE 2 real
diffofTE1


Segment 2
diff of LE 2 real


Segment 3
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
diff of LE 1 real
diff of LE 2 real
diff of TE 1 real
diff of TE 2 real


Segment 3
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
diff of LE 1 real
diff of LE 2 real
diff of TE 1 real
diff of TE 2 real


Segment4
0.10
-0.10
-0.20
-0.40
-0.50
diff real
diff of TE 2 real


Segment4
diff of LE 1 real
diff of LE 2 real
diff of TE 1 real
diff of TE 2 real

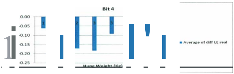
In Fig. 31 **the** averages of all the individual results for the change **in** lengthwith thc samc hungweighlfrom rhe leadingedge ofall scgmenlsonabil areplotted. likewise for the results from the trailing edges. This is done for both bilS. Where drillingwas doneata given hung weighl ut both a shallow and deeper deplh, the

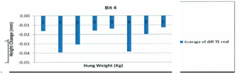
0.2 mm (atthc lcadingedgewith 3 and4Kg hungwcight on bit 4). The height loss on bit 5 atthc lcading edgewas aJittle lower, aboutO.1S mm.Atthc trailing cdge, thc hcightlosses wcresmallcr, lcss thanO.imm,but grcatcr onbit S than bit 4. There is no clear correlation with hung weight nor with holc dcpth (raw **data** shown in Table

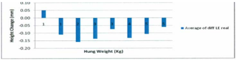
		Bit 4	
Date	Hung weight (kg)	**Average of diff LE real (mm)**	**Average of diff TE real (mm)**
		A,'crage ofdirrLE reaJ (mm)	A\'crage ofdiffTE real (mm)

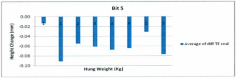
Thesmallerheightlossatthetrailingedgecomparcdtothcleadingcdgewasnol

cxpcctcd. as lhcre is liule or no change to the matrix surface at the leading edge on surface, *i.e.* on the tips of diamonds, Therefore this is a measure of wear of the









magnification Rcichcrt microscopewasuscd. Bccausccuningis mainly pcrfomlcdby diamondpJrticlcs, diamondparticlcwear is the mostimportantpJrtofthc bit wcar Two diamond particlcs, one from each bil (Fig. 32), which havc almoslthe same

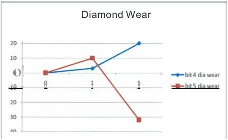
Thchighcr the magnificationofamicroscope objective used.lhcsmallcrthe deplh offocus. Thc Rcichcrl microscope has a graduated fine focus knob. By focllsing in tum on the tip ofa diamond and lhe surfaceofthc matrix beside, lhe diffcrcnce in heighlwasmcasurcd.Anx l6objectivewasuscdindarkfieldillumination. Table 6

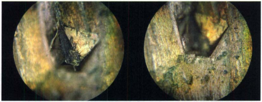
ca!culatcd from these. The surface on Aug 9th was testcd as the initial condition, fol!owcdbythcconditionsonAugll[lh] and It [h],aftcrdrillingwithhungweights 1

	Hung weight (kg)				
	Hung weight (kg)				

The height changes relative 10 the heights on Aug 9[lh] are plotted inFig.31.The height change for bit 5 in Ihcrun on Aug 12[lh] is different from that in all the other

the other runs show a decrease relative to surface aflerthc run on Aug9[lh].1fwe ignore the bit 5 run on Aug 12[th], there appears to be more height changewith bit 5

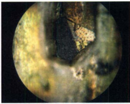




(a) Til} of diamond on Bil4on Aug9th **(b)MalrixsurfaceofBiI4on Aug9th**

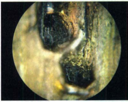
(c) Tip of diamond on Bit 4 on Aug 11th

(d) Matrix surface of Bit 4 on Aug 11th



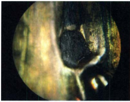
(e) Tip of diamond on Bit 4 on Aug 12th

(f) Matrix surface of Bit 4 on Aug 12th



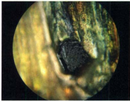
(g) Tip of diamond on Bit 5 on Aug 9th

(h) Matrix surface of Bit 5 on Aug 9th

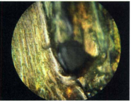


(i) Tip ofdialllond on BilSon Aug1 1lh

(j) Matrix surface of Bil Son Aug 11 lll

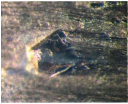
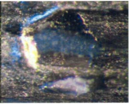
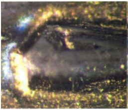
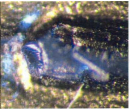
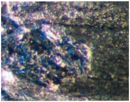


(k)TipofdiamondonBitSonAugIZ1h



(l) Matrix surface of Bit 5 on Aug 12th

have a surface covered with multiple sharp points (Fig. 34(c)) and grade into more severely fractured diamonds which may protrude very little from the matrix (Fig. 34(d)). Entire diamonds or residual fragments may be lost through pull-out to form holes in the bit matrix (Fig. 34(e)).

Chapter 4: Discussion and Future Recommendation

4.1SummaryofPrcsent\Vork

ofcarlyslagc in thedc\'clopment of new tcchnology in vibration assistcdrotary drilling. Al lhis stage. a small laboralorydrill rig is uscd,upto now with vcry short drillingruns.producingsmallamountofcuttingloolwearthatarcdifficullio

Thc tcchniqucs developed and uscd mainly in\'ol\'c microscopy and surface replication, Replicas have proven to be valuable tcchniquc of measuringhcightloss using indcm3tions as reference poinls. Thisappcars promising. bUl may nccd somc

sludy.Thcchangcin length of the bit segmcnlsobservcd inlhc tcsts reported here was muinly duc to the change in height ofprotfudingdiamonds caused by wear and

The diamond particle wear was measund by the Wild microscopcvisually,and

scc Ihc profile change oflhe diamond particle. Comparinglhe pancm ofdiamond

leading edge, morc sevcrc diamond wear was **obtained** at trailing edge,which could bcdemonSlrated bylhe Fig. 27 as well. From **Fig.** 30. il was clear to scc Ihatthe segmcniproduccd by lhesamehung weighLDuC10 lhcshonpcnCiraiiondeplhof

chal lcngcsnccdtoovercome,suchassoshortdrill ingdepthofeachdrilling and that

no hungweighl morclhan 7 Kg can bc applied on Ihestccl wheel. Thcrefore, because

drilling fonnalion. so lhere was no comparison oflhc bit wcar in different types of

CffCCl of rotary spced on Ihebil wear was not able to be investigated

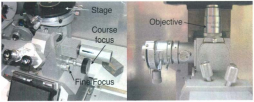
viewing axis. like a hollow coneoflighl. Sowhcn asmoolh surface.perpendicularto

rough surface the path of the light isscallcredin many directions,and lhcimagccan

projcci have a rough surface and therefore dark field illuminalion is lhe main lypeof kccpinmindisalignmenl.ltisvcryimportanlthatlhcfc3lurcof inlcreslisorienled perpendicular to the line of sight. If the feature is not perpendicular, part of the field

is done by measuring the change in the fine focus knob position. when the top of the

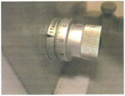
supply box on the floor. direclly next 10 the microscope. from Ex to In.then press the only be turned on once a day. So when using the Reichert, only lum off the



Ncxl place specimen on stage and bring surface oflhc spccimcn into focus using

powcrmagnification. This can be done by replacing lhc low power objcciivcwith a

highcr onc by raising thc slage and replacing the objectivc. Asmentionedearlier in thisappendi)(itissuggestedthateachoperalorbecomecomfortableusingthe



It is possible to measurethe depths and c1evationson the Reichert **because of the**

of the change in position of the knob when diffcrellt levels of clevation arc in focus. a

ThcWildmicroscopcwillprimarilybeuscdwilhthccamcraforpholOgraphyand

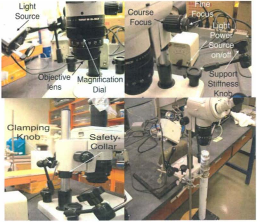
will n0l onlyscrve as a pennanenl record of the state of lhc drill bitbetween each drilling. bUI as a method to measure the distance from edges to indentations by using a part of the sctup. To set up the lighting align onc light at a timconto lhe arca in which

then finally tum both on l0 view lhe spccimen. Ha\'ingthe fieldofvieworientedina

pcrpcndicular dircction to lhe line of sight is also important on the Wild to ensure

onthe lightpowcrsource(botlomlcft). exl. following lhe mcthod described earlier

in lhis **section**, align the lights one at a time, using the support knobs tomovc lhclight


Light
Source
Objective
lens
Magnification
Dial
Course
Focus
Fine
Focus
Light
Power
Source
on/off
Support
Stiffness
Knob
Clamping
Knob
Safety
Collar

bcdone by placing lhe bit on a sioolorstand. with thecultingcnd facingupwards, Appcndix B: Using lhc Camcra

Using a camera 10 document and measure wear on the drill bits is very useful. By taking photographs of the drill bits a pcmluncnt record is created of theappearanceof

Thegrcatcstconcem while tuking photographs is lhcimponancetoestablishthe

pholograph must also be printed at the Simc size and mcthod to avoid anincorrect

then aflcr printing the picture measurc Ihcdistancebctwccn incrcmcnts oll lhcphoto

procedurc l0 calibratc using the Reichert isthcsarnc,cxccPl using a1 nunscalc

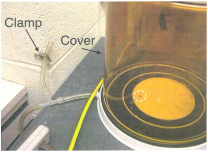
It is also appropriate l0 nOlcthat while taking a picture while zoominginonthe

importanllobcconsistenlwiththecamcrascttingswhilclakingpicturesofdifTcrcnt

Whcn prinling the photographs carc must betaken with thc scttingsof theprinl

magnification as compared to if the **picture does** not fill the page. This will mean Ihal

Appendix C: Vacuum Chamber



Air
Ballast

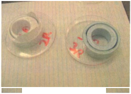
ON/Off
Switch

Appendix 0 : Procedure for Replication

(6) Aftcrthebubbleshavebecn removed,

of the negative (two completed

When the majority of bubbles have been evacuated from the epoxy mixture,



vacuum until virtually all bubbles

Appendix E: The Gold Coater Operation

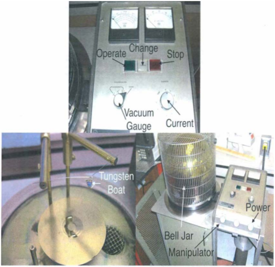
(7) Chcck the bell jar pressure meter with vacuum gauge set to pirani; the

(8) Tum manipulalOron to rotate the specimen to ensure that all sidesarccoated

Adjusl current knob until evaporating current metcrrcads 10 amps. approximately6or7onlhepotenliomcter(currenlknob),holduntil the gold isevaporatcd.Usuallylheboatandthemeltinggoldcanbe sccn throughthe bell jar (Iflhe bell jar is clean wear dark glasses forcyc protcction)

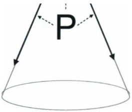
Prcsschange,andwaituntil itispossibleloopenthebelljar. Opcn the bell jar and remove the samples (if there is insufficient covcragcrepcat steps 5-9

Closc thc belljarand pressopcrate, waitapprox illlately lOsecondsandpress


Operate
Change
Stop
Vacuum Gauge
Current
Tungsten Boat
Bell Jar
Manipulator
Power


210 220 230 240 250 260 270 280 290 300

Appendix G: Surface Tension


P

AppendixH:Nomenclature