| |
|---|
| **Faculty of Engineering**<br>**Stellenbosch University**<br>**Fakulteit Ingenieurswese**<br>**Universiteit Stellenbosch** |

| | | | |
|---|---|---|---|
| **Materials Science A244**<br>**Materiaalkunde A244** | | | **Assessment 1**<br>September 2024<br>**Assessering 1**<br>September 2024 |
| **Duration**<br>**Tydsduur** | **2 h / ure** | **Full marks**<br>**Volpunte** | **120**<br>**(4 bonus)** |

| | Names<br>Name | Signatures to confirm: Question paper and marking scheme are correct and aligned with module outcomes<br>Handtekeninge ter bevestiging: Vraestel en merkskema is korrek en belyn met module uitkomste |
|---|---|---|
| Examiner(s)<br>Eksaminator(e) | Prof D Blaine<br>Dr M Neaves | |
| Moderator(s)<br>Moderator(e) | Mr P Blaine | |

DO NOT WRITE IN THIS AREA – MOET NIE IN HIERDIE GEBIED SKRYF NIE

| Q1 [12] | Q2 [12] | Q3 [10] | Q4 [22] | Q5 [26] | Q6 [17] | Q7 [25] | TOTAL/ *TOTAAL* [124] |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

**INSTRUCTIONS ON NEXT PAGE – INSTRUKSIES OP VOLGENDE BLADSY**

| Student No: |
|---|
| |

| Instructions | Instruksies |
| --- | --- |
| The Engineering Faculty's "General Stipulations for Under- and Postgraduate Modules" apply to this assessment. | Fakulteit Ingenieurswese se "Algemene Bepalings vir Voor- en Nagraadse Modules" is op hierdie assessering van toepassing. |
| Answer all the questions. | Beantwoord al die vrae. |
| The marks for each question are indicated to the right of the question in square brackets. | Die punte vir elke vraag word regs van die vraag in vierkantige hakies aangedui. |
| This is a **closed book assessment**. | Hierdie is 'n **toeboek assessering**. |
| **Pocket calculators** prescribed for the first two years of the BEng may be used. | **Sakrekenaars** voorgeskryf vir die eerste twee jaar van die BIng mag gebruik word. |
| **Write your student number on the front page and in the corner of each page, in the space provided.** | **Skryf u studente nommer op die voorblad en in die spasie wat in die hoek van elke bladsy verskaf word.** |
| **Answer each question in the space provided on the question paper** and ensure that your final answers are clearly indicated. | **Antwoord elke vraag in die spasie wat op die vraestel verskaf word** en maak seker dat u finale antwoorde word duidelik aangedui. |
| You may use the blank pages at the end of the question paper for additional space to write or to do calculations. | U kan die oop bladsye aan die einde van die vraestel gebruik vir addisionele spasie om te skryf of om berekeninge te doen. |
| **THE ENTIRE QUESTION PAPER WITH THE ANSWERS FILLED IN MUST BE HANDED IN.** | **DIE HELE VRAESTEL MET INGEVULDE ANTWOORDE MOET INGEDIEN WORD.** |

Student No:

## **Question 1 / *Vraag 1*** [12]

With reference to their material category, atomic bonding and subatomic particle arrangements for each of these materials, explain why they exhibit the indicated properties.

*Met verwysing na hul materiaalkategorie, atoombinding en subatomiese partikel rangskikkings vir elkeen van hierdie materiale, verduidelik hoekom hulle die aangeduide eienskappe vertoon.*

1.1

Copper (Cu) wire and foil is used for electrical connections as it is highly electrically conductive. Why? (5)

*1.1*

*Koper (Cu) draad en foelie word gebruik vir elektriese verbindings aangesien dit hoogs elektries geleidend is. Hoekom? (5)*

1.2

Borosilicate glass ($SiO_2$ with >8% $B_2O_3$) is used for chemical laboratory glassware (beakers, cylinders, etc.) as it is chemically resistant and has a high melting temperature. Why? (7)

*1.2*

*Borosilikaatglas ($SiO_2$ met >8% $B_2O_3$) word gebruik vir chemiese laboratoriumglasware (bekers, silinders, ens.) aangesien dit chemies bestand is en 'n hoë smelttemperatuur het. Hoekom? (7)*

Student No:

## Question 2 / *Vraag 2* [12]

2.1 Figure 2.1 shows a unit cell. Answer the questions that follow.

*2.1 Figuur 2.1 toon 'n eenheidsel. Beantwoord die vrae wat volg.*

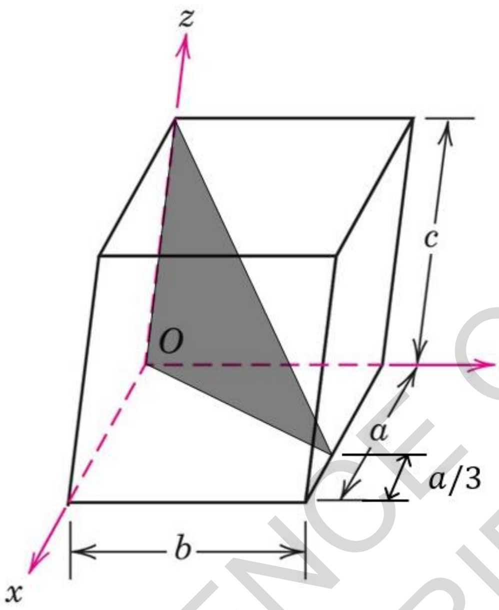



Figure 2.1 / *Figuur 2.1*

2.1.1 (3)

For a cubic unit cell, state the relationship between side lengths $a, b, c$, as well as the relationship between the interaxial angles $\alpha, \beta, \gamma$. Note, $\alpha$ is the angle between the unit vectors of the $z$ and $y$ axes, $\beta$ between the $x$ and $z$ axes, and $\gamma$ between the $x$ and $y$ axes.

*2.1.1* *(3)*

*Vir 'n kubieke eenheidsel, noem die verwantskap tussen sylengtes $a, b, c$ asook die verwantskap tussen die tussenashoeke $\alpha, \beta, \gamma$. Let wel, $\alpha$ is die hoek tussen die eenheidsvektore van die $z$- en $y$-asse, $\beta$ tussen die $x$- en $z$-asse, en $\gamma$ tussen die $x$- en $y$-asse.*

2.1.2 (9)

Determine the Miller indices for the shaded plane in Figure 2.1, assuming that the conditions for a cubic unit cell are met (as defined in Question 2.1.1). All calculations and any supporting sketches <u>must</u> be shown; space for this is provided on the next page.

*2.1.2* *(9)*

*Bepaal die Miller-indekse vir die ingekleurde vlak in Figuur 2.1, met die veronderstelling dat die voorwaardes vir 'n kubieke eenheidsel nagekom word (soos gedefinieer in Vraag 2.1.1). Alle berekeninge en enige ondersteunende sketse <u>moet</u> getoon word; spasie hiervoor word op die volgende bladsy voorsien.*

Student No:

Student No:

**Question 3 / *Vraag 3*** **[10]**

3.1
Polymers can exhibit a degree of crystallinity. Figure 3.1 shows the structure of a semicrystalline polymer.

*3.1*
*Polimere kan 'n mate van kristalliniteit vertoon. Figuur 3.1 toon die struktuur van 'n semikristallyne polimeer.*

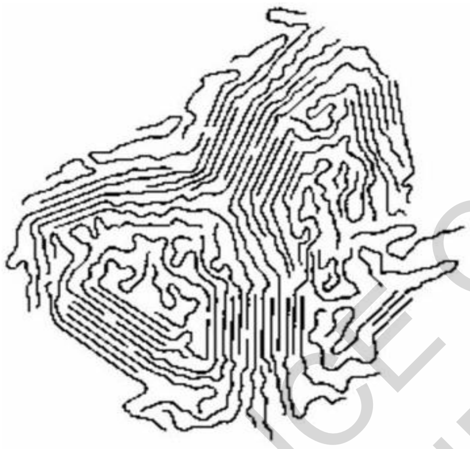


Figure 3.1 / *Figuur 3.1*

3.1.1 (2)
Clearly circle and label examples of crystalline and amorphous regions on Figure 3.1.

*3.1.1* *(2)*
*Omkring en gee byskrifte vir voorbeelde van kristallyne en amorfe gebiede duidelik op Figuur 3.1.*

3.1.2 (4)
Describe the difference between the structure of the crystalline and amorphous regions of this semicrystalline polymer.

*3.1.2* *(4)*
*Beskryf die verskil tussen die struktuur van die kristallyne en amorfe gebiede van hierdie semikristallyne polimeer.*

| Student No: |
|---|
| |

3.2

Figure 3.2 shows a characteristic ceramic structure.

*3.2*

*Figuur 3.2 toon 'n kenmerkende keramiekstruktuur.*

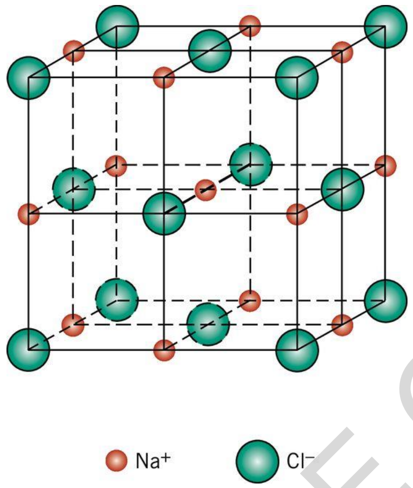



Figure 3.2 / *Figuur 3.2*

3.2.1 (1)

Label one cation and one anion, respectively, in this structure, directly on Figure 3.2.

*3.2.1 (1)*

*Gee byskrifte vir een katioon en een anioon, onderskeidelik, in hierdie struktuur, direk op Figuur 3.2.*

3.2.2 (3)

Provide the following characteristics of this structure:

*3.2.2 (3)*

*Verskaf die volgende kenmerke van hierdie struktuur:*

(i) Type (AX, $A_mX_p$, $A_mB_nX_p$):

*(i) Tipe (AX, $A_mX_p$, $A_mB_nX_p$)*

| |
|---|
| |

(ii) Coordination number:

*(ii) Koördinasienommer:*

| |
|---|
| |

(iii) Coordination geometry name (linear, planar equilateral triangle, tetrahedron, octahedron, cube):

*(iii) Koördinasie geometrie naam (lineêr, gelyksydige driehoekvlak, tetraëder, oktaëder, kubus):*

| |
|---|
| |

Student No:

## Question 4 / *Vraag 4* [22]

Table 4.1 provides some characteristics of selected elements.

*Tabel 4.1 verskaf 'n paar kenmerke van geselekteerde elemente.*

| Element | Atomic number/ *Atoom-nommer* | Crystal structure at 20 °C / *Kristalstruktuur by 20 °C* | Atomic radius / *Atoom radius* [nm] | Most common valency / *Mees algemene valensie* | Electro-negativity / *Elektro-negatiwiteit* | Density at 20 °C / *Digtheid by 20 °C* [g/cm$^3$] |
|---|---|---|---|---|---|---|
| Aluminium | 13 | FCC / *VSK* | 0.143 | 3+ | 1.5 | 2.71 |
| Copper / *Koper* | 29 | FCC / *VSK* | 0.128 | 1+ | 1.9 | 8.94 |
| Iron ($\alpha$) / *Yster* ($\alpha$) | 26 | BCC / *BSK* | 0.124 | 2+ | 1.8 | 7.87 |

4.1

Consider the data for the elements Al and Fe.

*4.1*

*Beskou die data vir die elemente Al en Fe.*

4.1.1 (6)

Calculate the volume for an Al and Fe unit cell, respectively. Repeat the calculation for each element, showing all your working steps with clear explanations.

*4.1.1* *(6)*

*Bereken die volume vir 'n Al- en Fe-eenheidsel, onderskeidelik. Herhaal die berekening vir elke element, en wys al u werkstappe met duidelike verduidelikings.*

4.1.2 (7)

With the limited data provided in Table 4.1, provide a <u>rational explanation</u> as to why the density of Al is so much lower than that of Fe.

*4.1.2* *(7)*

*Deur die beperkte data wat in Tabel 4.1 verskaf word, gee 'n <u>rasionele verduideliking</u> waarom die digtheid van Al soveel laer is as dié van Fe.*

Student No:

Consider that the density of a metal is correlated to the mass of the atoms contained inside a unit cell, per unit cell volume. The equation for the metal density is provided in the formula sheet for guidance in your reasoning, however you do NOT need to calculate the density and indeed this is not possible without the atomic weight, which is not provided.

*Neem in ag dat die digtheid van 'n metaal gekorreleer word met die massa van die atome wat binne 'n eenheidsel voorkom, per eenheidselvolume. Die vergelyking vir metaaldigtheid word in die formulablad verskaf as leiding vir jou redenering, alhoewel u hoef NIE die digtheid te bereken nie en dit is beslis nie doenbaar nie sonder die atoomgewig nie, wat nie verskaf word nie.*



4.2 (9)

Use the data provided to determine whether Al will form a substitutional solid solution with Cu.

*4.2 (9)*

*Gebruik die data wat verskaf word om te bepaal of Al 'n substitusionele vaste oplossing met Cu sal vorm.*

Student No:

**Question 5 / Vraag 5** **[26]**

5.1

In manufacturing operations where forming occurs by cold work, a recrystallisation heat treatment is often used between steps. Consider the following manufacturing process that consists of 3 steps:

Step 1: Cold draw a rod from an original diameter, $D_0$, to an intermediate diameter, $D_1$, resulting in 30% cold work.

Step 2: Recrystallisation heat treatment, after which the diameter is $D_R$.

Step 3: Cold draw to a final diameter of $D_f$, resulting in 20% cold work.

*5.1*

*In vervaardigingsbedrywighede waar vorming deur koue werk plaasvind, word 'n herkristallisasie-hittebehandeling dikwels tussen stappe gebruik. Oorweeg die volgende vervaardigingsproses wat uit 3 stappe bestaan:*

*Stap 1: Koudtrek 'n staaf van 'n oorspronklike deursnee, $D_0$, na 'n tussendeursnee, $D_1$, wat 30% koue werk tot gevolg het.*

*Stap 2: Herkristallisasie hittebehandeling, waarna die deursnee $D_R$ is.*

*Stap 3: Koue trek tot 'n finale deursnee van $D_f$, wat lei tot 20% koue werk.*

5.1.1 (12)

Indicate whether the dimensions or properties shown are > (greater than), < (less than), or = (equal to) each other. In all cases, subscript

0 refers to the original condition,
1 is after Step 1,
R is after Step 2, and
f is after Step 3.

*5.1.1 (12)*

*Dui aan of die afmetings of eienskappe wat gewys word > (groter as), < (minder as) of = (gelyk aan) mekaar is. In alle gevalle, onderskrif*

*0 verwys na die oorspronklike toestand,*
*1 is na Stap 1,*
*R is na Stap 2, en*
*f is na Stap 3.*

| | Step 0 → Step 1 | | Step 1 → Step 2 | | Step 0 → Step 3 | |
|---|---|---|---|---|---|---|
| | Change from original state to after 1st cold draw / *Verandering vanaf oorspronklike toestand tot ná 1ste koue trek* | | Change from after 1st cold draw to after recrystallisation heat treatment / *Verandering vanaf ná 1ste koue trek tot ná herkristallisasie hittebehandeling* | | Overall change from original state to final state (after 2nd cold draw) / *Algehele verandering vanaf oorspronklike toestand ná finale toestand (ná 2de koue trek)* | |
| Diameters / *Deursnee* | $D_0$ | $D_1$ | $D_1$ | $D_R$ | $D_0$ | $D_f$ |
| Elastic modulus / *Elastisiteitsmodulus* | $E_0$ | $E_1$ | $E_1$ | $E_R$ | $E_0$ | $E_f$ |
| Yield strength / *Swigsterkte* | $\sigma_{y,0}$ | $\sigma_{y,1}$ | $\sigma_{y,1}$ | $\sigma_{y,R}$ | $\sigma_{y,0}$ | $\sigma_{y,f}$ |
| Ductility, %EL / *Rekbaarheid, %EL* | $\%EL_0$ | $\%EL_1$ | $\%EL_1$ | $\%EL_R$ | $\%EL_0$ | $\%EL_f$ |

5.1.2 (6)

Explain why the properties for elastic modulus, yield strength and ductility show the behaviour you have indicated. Indicate what changes at an atomic level in the crystal lattice at each step as a means to support your argument.

*5.1.2 (6)*

*Verduidelik waarom die eienskappe vir elastisiteitsmodulus, swigsterkte en rekbaarheid die gedrag toon wat u aangedui het. Dui aan wat op 'n atoomvlak in die kristalrooster by elke stap verander as 'n manier om u argument te ondersteun.*



5.2

Figure 5.2 shows a crystal lattice with dislocations.

*5.2*

*Figuur 5.2 toon 'n kristalrooster met ontwrigtings.*

5.2.1 (3)

Identify the dislocations in Figure 5.2 by drawing in the standard ⊥ dislocation indicator, orientated correctly according to the structure of the dislocation.

*5.2.1 (3)*

*Identifiseer die ontwrigtings in Figuur 5.2 deur die standaard ⊥ ontwrigting-aanwyser in te teken, korrek georiënteer volgens die struktuur van die ontwrigting.*

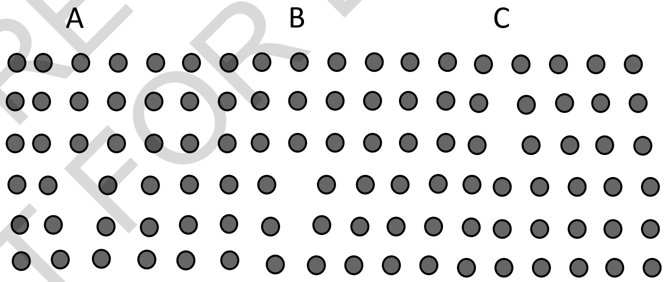



Figure 5.2 / *Figuur 5.2*

5.2.2 (3)

Select the correct type of dislocation at each of the positions by marking the correct box with an X:

*5.2.2 (3)*

*Kies die korrekte tipe ontwrigting by elkeen van die posisies deur die korrekte blokkie met 'n X te merk:*

| *Dislocation position / Ontwrigtingposisie* | *Edge / Kant* | *Screw / Skroef* | *Mixed / Gemeng* |
|---|---|---|---|
| *A* | | | |
| *B* | | | |
| *C* | | | |

| Student No: |
|---|
| |

5.2.3 (1)

What happens when the dislocation at A migrates to B?

*5.2.2 (1)*

*Wat gebeur wanneer die ontwrigting by A na B toe skyf?*

5.2.4 (1)

What happens when the dislocation at C migrates to B?

*5.2.3 (1)*

*Wat gebeur wanneer die ontwrigting by C na B toe skyf?*

## Question 6 / Vraag 6 [17]

6.1

The diffusion coefficients of Zn in Cu at two different temperatures are given in Table 6.1 below.

*6.1*

*Die diffusiekoëffisiënte van Zn in Cu by twee verskillende temperature word in Tabel 6.1 hieronder gegee.*

| Temperature / *Temperatuur* | Diffusion coefficient / *Diffusiekoëffisïent* |
|---|---|
| $750℃$ | $5.31 \times 10^{-15}\ \ \mathrm{m^2/s}$ |
| $850℃$ | $3.84 \times 10^{-14}\ \ \mathrm{m^2/s}$ |

6.1.1 (6)

Draw the diffusion curve for Zn in Cu on the graph paper provided on the next page. Add axis titles with units, as well as appropriate scale values on the x and y axes of the semi-logarithmic graph.

*6.1.1 (6)*

*Teken die diffusiekurwe vir Zn in Cu op die grafiekpapier wat op die volgende bladsy verskaf word. Voeg astitels met eenhede by, asook geskikte skaalwaardes op die x en y asse van die semilogaritmiese grafiek.*

6.1.2 (7)

A minimum steady-state diffusion flux for Zn in Cu of $J = 1 \times 10^{-15}\ \ \frac{\mathrm{kg}}{\mathrm{m^2/s}}$ is required. The concentration gradient is $-50\ \frac{\mathrm{kg/m^3}}{\mathrm{m}}$. Calculate the diffusion coefficient required to achieve this diffusion flux, and use the diffusion curve drawn on the graph to determine the minimum temperature (℃) required to achieve this diffusion flux. Clearly indicate this point on the graph.

*6.1.2 (7)*

*'n Minimum bestendige-toestand diffusie vloed vir Zn in Cu van $J = 1 \times 10^{-15}\ \ \frac{\mathrm{kg}}{\mathrm{m^2/s}}$ word benodig. Die konsentrasiegradiënt is $-50\ \frac{\mathrm{kg/m^3}}{\mathrm{m}}$. Bereken die diffusiekoëffisiënt wat benodig word om hierdie diffusievloed te bereik, en gebruik die diffusiekurwe wat op die grafiek geteken is om die minimum temperatuur (℃) te bepaal, wat benodig word om hierdie diffusievloed te bereik. Dui hierdie punt duidelik op die grafiek aan.*

Student No:

6.1.3 (4)

The diffusion coefficient curve is described by an Arrenhius temperature dependence. Explain in your own words the mathematical description of this type of temperature dependence.

*6.1.3 (4)*

*Die diffusiekoëffisiëntkurwe word deur 'n Arrenhius-temperatuurafhanklikheid beskryf. Verduidelik in u eie woorde die wiskundige beskrywing van hierdie tipe temperatuurafhanklikheid.*

Student No:

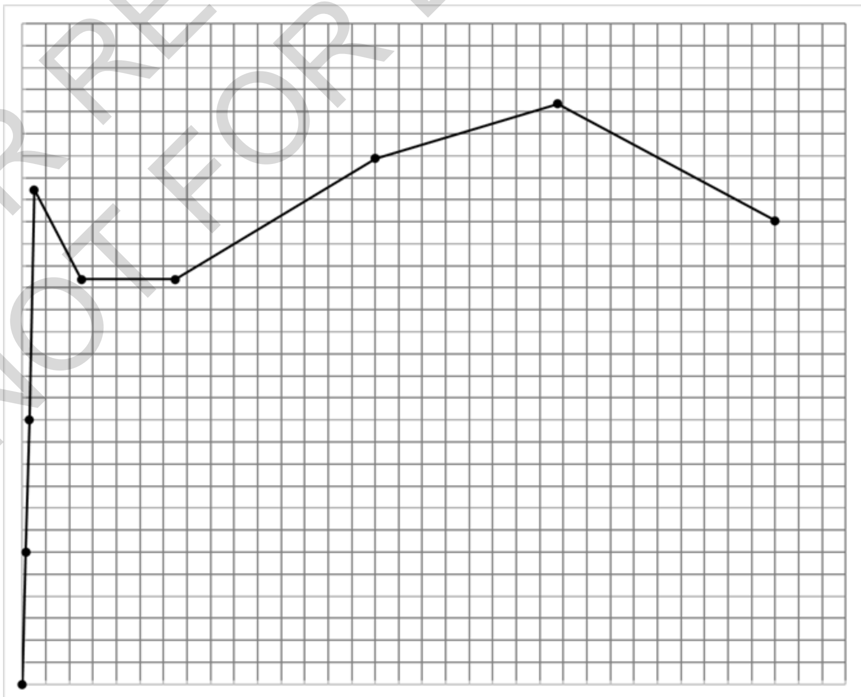
Student No:

## Question 7 / Vraag 7 [25]

A 12 mm-diameter rod is machined from a sample of plain carbon steel alloy and is subjected to uniaxial tensile testing, according to the ASTM E8M standard. An extensometer with a length between arms of 40 mm is used to measure elongation, while the applied force is measured with a 150 kN-load cell. The following data are recorded during the test.

*'n Eenassige trektoets word op 'n staaf met 'n deursnit van* 12 mm *toegepas, volgens die ASTM E8M-standaard. Die staaf is gemasjineer uit 'n monster van 'n gewone koolstofstaal-allooi. 'n Verlengingsmeter met 'n lengte tussen arme van* 40 mm *word gebruik om verlenging te meet, terwyl die toegepaste krag met 'n* 150 kN-*lassel gemeet word. Die volgende data word tydens die toets opgeneem.*

| | Elongation / *Verlenging* [mm] | Load / *Las* [kN] | |
|---|---|---|---|
| | 0 | 0 | |
| | 0.06 | 34 | |
| | 0.12 | 68 | |
| | 0.2 | 127 | |
| | 1.0 | 104 | |
| | 2.6 | 104 | |
| | 6 | 135 | |
| | 9.1 | 149 | |
| | 12.8 | 119 | |
| | Failure / *Breuk* | | |



Student No:

7.1 (11)

The force-elongation data provided has been used to draw the **stress-strain curve** for this material on the grid provided on the previous page.

*7.1 (11)*

*Die gegewe las-verlengingsdata is gebruik om die* ***spanning-vervormingskurwe*** *vir hierdie materiaal te teken op die blokgrafiek wat op vorige bladsy verskaf word.*

7.1.1

The curve demonstrates an abrupt elastic-plastic transition. What is the name of this phenomenon?

*7.1.1*

*Die kurwe toon 'n skielike elasties-plastiese oorgang. Wat is die naam van hierdie verskynsel?*

7.1.2

Add axis titles with units, as well as appropriate scale values on the x and y axes of the grid.

*7.1.2*

*Voeg astitels met eenhede by, asook geskikte skaalwaardes op die x en y asse van die blok grafiek.*

7.1.3

Clearly indicate **on the graph** stress and strain values for the yield points, tensile strength and fracture strength.

*7.1.3*

*Dui die spanning en vervormingwaardes duidelik* ***op die grafiek*** *aan vir die swigpunte, treksterkte en breuksterkte.*

7.2 (2)

Calculate the elastic modulus for this material.

*7.2 (2)*

*Bereken die elastisiteitsmodulus vir hierdie materiaal.*

7.3 (2)

Of the two yield points shown in the curve, which one should be taken as the yield strength of this material? Also give a brief reason for your choice.

*7.3 (2)*

*Van die twee swigpunte wat in die kurwe getoon word, watter een moet as die swigsterkte van hierdie materiaal geneem word? Gee ook 'n kort rede vir jou keuse.*

Student No:

7.4 (3)

Calculate the approximate toughness of the material.

*7.4 (3)*

*Bereken die benaderde taaiheid van die materiaal.*

7.5 (5)

What is the total gauge length of the specimen <u>after</u> failure? Give your answer to 3 significant figures. Indicate the construction line(s) used to determine the value on the stress-strain diagram **or** clearly show how you determined the value by calculations.

*7.5 (5)*

*Wat is die totale maatlengte van die toetsstuk <u>ná</u> faling? Gee u antwoord tot 3 beduidende syfers. Dui die konstruksielyn(e) aan wat gebruik word om die waarde te bepaal op die spannings-vervormings kurwe* ***of*** *wys berekeninge wat duidelik aandui hoe u die waarde bepaal het.*

7.6 (2)

Suppose the Brinell hardness of the tested steel is 382 HB, whereas the hardness of an alternative steel alloy is 400 HB. Which steel (tested or alternative) likely has a higher tensile strength? Give a brief reason for your answer.

*7.6 (2)*

*Gestel die Brinell-hardheid van die getoetste staal is 382 HB, terwyl die hardheid van 'n alternatiewe staalallooi 400 HB is. Watter staal (getoets of alternatief) het waarskynlik 'n hoër treksterkte? Gee 'n kort rede vir jou antwoord.*

Student No:

PAGES LEFT INTENTIONALLY BLANK FOR ADDITIONAL CALCULATIONS OR WRITING SPACE /
*BLADSYE DOELBEWUS LEEG GEHOU VIR ADDISIONELE BEREKENINGE OF SKRYFRUIMTE*

Student No:

PAGES LEFT INTENTIONALLY BLANK FOR ADDITIONAL CALCULATIONS OR WRITING SPACE /
*BLADSYE DOELBEWUS LEEG GEHOU VIR ADDISIONELE BEREKENINGE OF SKRYFRUIMTE*