Question 1

(a)

True Stress $\sigma = 700(\varepsilon)^{0.2}\, MNm^{-2}$

$$r = \frac{A_0 - Af}{A_0} = \frac{Wt_0 - Wtf}{Wt_0} = 1 - \frac{tf}{t_0} \quad 0.5 = 1 - \frac{tf}{to} \quad tf = 0.5to \quad r = 0.5$$

Because it is a bar, it can be considered 2 dimensional A0=Wt0

True Strain $\varepsilon = \ln\left[\frac{1}{(1-r)}\right]$ Substituting r = 0.5 $\varepsilon = \ln\left[\frac{1}{(1-0.5)}\right]$ $\varepsilon = 0.693$

Yield Strength $\sigma = K\varepsilon^{n}$ Where ε is the true strain

K = Strength Coefficient = 700

n = Work hardening Exponent = 0.2

ε = True strain = 0.693

Substituting $\sigma = 700(0.693)^{0.2}\, MNm^{-2}$ $\sigma = 650.5 MNm^{-2}$

The yield strength or limit since the bar will start to deform plastically is 650.5 MNm^{-2}

(b)

Working with the same material means working with the same strength coefficient (K) and the same work hardening exponent (n). Therefore, the equation for True stress will remain

True Stress $\sigma = 700(\varepsilon)^{0.2}\, MNm^{-2}$

First it is intended to find the true strain for that given yield strength (σ = 525 MNm^{-2})

$$\sigma = 700(\varepsilon)^{0.2}\, MNm^{-2} \quad 525 = 700(\varepsilon)^{0.2} \quad \log 525 = \log 700 + 0.2\log(\varepsilon) \quad \varepsilon = 0.2369$$

Once we have calculated the yield strength, the final amount of cold work will be given related with the reduction.

$$\varepsilon = \ln\left[\frac{1}{(1-r)}\right] \quad 0.2369 = \ln\left[\frac{1}{(1-r)}\right] \quad e^{0.2369} = \left[\frac{1}{(1-r)}\right] \quad r = 0.211$$

The reduction is the sum of the initial cold work plus the final cold work

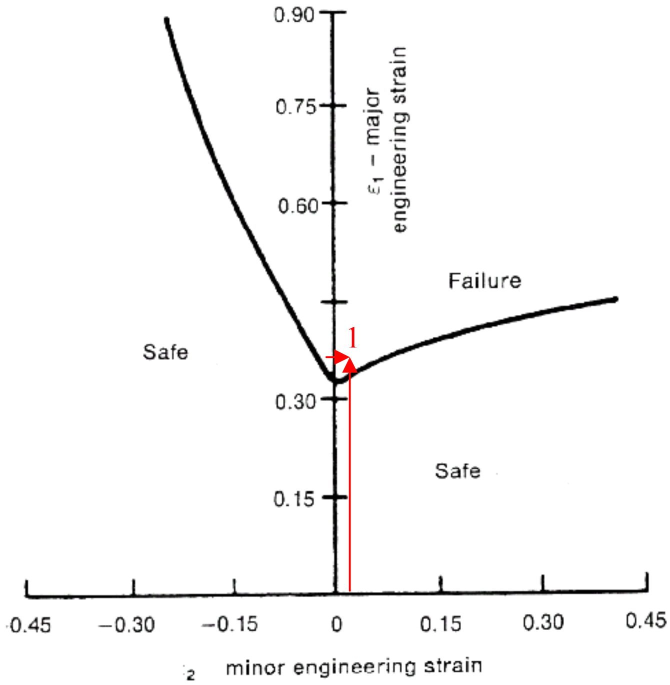
$r = unknown + 15\% \quad 0.211 - 0.15 = unknown$

The unknown amount of cold work was 0.06 or **6%**

(c)

The pressing failed because for that combination of major and minor engineering strain stresses, the point lays in the failure zone. *See point 1*

It is evident looking at the FLD that the presence of a tensile minor engineering strain reduces drastically the available strain before breaking.



To successfully make this part by press forming, the point (given by major and minor engineering strains applied) must lie under the necking curve. This can be done by different ways. One of them would be to apply a compressive minor engineering strain; this will move the point to the left side of the graph, to the safe area. The part can be cone in two stages, or deep drawing. With this technique the difference of thickness in the material is minimized under the die. With lubrication and a reduced die radius, the necessary thickness can be achieved to reduce the minor engineering strain thanks to compressive stresses.

Question 2

(a)

(i)

The plain strain fracture toughness is deducted from the equation
$K_{1c} = Y\sigma\sqrt{\pi a}$

Being σ the necessary stress for the propagation of a crack, Y the geometric constant and ‘a’ the depth of a surface crack.

Substituting Y = 1; depth of crack a = $0.1*10^{-6}$m and σ = 140 MNm^{-2}

$K_{1c} = Y\sigma\sqrt{\pi a}$ $K_{1c} = 1*140\sqrt{\pi * 0.1*10^{-6}}$ $K_{1c} = 0.078 MNm^{-3/2}$

(ii)

As plain stress remains the same, and the applied stress σ = 30 MNm-2

The maximum allowable flaw size has become: $a = \frac{1}{\pi}\left(\frac{K_{1c}}{\sigma Y}\right)^2$ $a = \frac{1}{\pi}\left(\frac{0.078}{30*1}\right)^2$
$a = 6.76*10^{-6} m$

The size of the maximum flaw will be 6.76 um.

The rate of grown $Rg = \frac{S_{final} - S_{initial}}{\min utes} = \frac{6.76*10^{-6} - 0.1*10^{-6}}{2.16*10^4} = 3.08*10^{-10} m/\min$

(b)

Ceramics itself have a very large lattice resistance, given by the abundance of covalent bonds. Dislocations (causes of cracks) need high stress to move through the covalent bonds structure. This results in a high integrity to corrosion and reduced ductility or plastic deformation, but also brittleness (not adequate for impact stress). Added to this, it is very difficult to get rid of cracks and flaws originated in the production process (pores, thermal stress originated during the cooling phase).

To strengthen ceramics we must look for ways of making fracture more difficult beginning by the equation for critical stress in ceramics

$\sigma t_s = \frac{K_{1c}}{\sqrt{\pi a}}$ Where K_{1c} is the toughness of the material and 'a' is the flaw size.It seems evident that the two ways to increase the toughness could be or increase K_{1c} (difficult because it is a property of the material) or reduce the flaw size a.

New developments in technology of materials lead some researchers to experiment with the conductivity of materials. Ceramics, usually known as non-conductive were going to be tested for new conductive aplications. The researchers included carbon nanotubes, known for their conductivity and high strength into pure alumina ceramics. The composites were prepared under pressing furnaces with fine powder alumina. When an electric field was applied, the nanotubes got oriented in parallel with this field creating a matrix inside the composite. The conductivity test was successful, but what was more interesting was the increased toughness of the ceramics. Nanotubes absorbed a percentage of the fracture energy by creating bridges between the alumina grains. Usually are these boundaries the weakest links where cracks propagate. As it is mention by Zhu, Y. et al (2007) only the nanotubes perpendicular to the fracture direction were effective, but orientation of nanotubes can be feasible when applying an electric field.

Similarly, glasses have been toughened with reinforcement matrix. The characteristics of the materials chosen for these matrixes are high strength or high ductility. It has been widely tested the application of silicon carbide matrixes for transferring the load from the crystalline structure to the fibres. These methods intend to increase the Young's module of the composite ('Y' as has been discussed before) See Brennan, J.J. (1982). Other experiments intend to introduce in the crystal structure foreign particles pretending to trap and deflect the energy of the crack. These inserts lead to the creation of strong bonds with the glass. A good example of this practice is the doping with alumina platelets from Kotoul, M et al (2007). The platelets were hexagonal shaped, and added while manufacturing. They resulted into "tangential compressive and radial tensile stresses in the matrix" that improved the toughness of the material.

Question 3

(a)

Casting consists basically in pouring a molten metal into a mould with a desired shape. When the metal cools down, it solidifies. Despite the numerous methods for casting process (sand moulds, permanent moulds, pressurized casting, etc) porosity and inclusions are normally present.

To avoid porosity, different cures can be adopted. The metal can be degassed (remove dissolved gasses) while in the liquid phase by adding reactive chemicals or casting in vacuum or pressure tight.

When the metal cools down and crystallizes, it shrinks. This change of phase, if it is not controlled can create cavities. The most common way to prevent this is by using feeders (raisers) that continue topping up the mould during the crystallization, and favour the contraction or cavity associated to be formed in the feeder instead of being in the mould. Other solution that can be applied in special cases is the use of continuous casting, where the mould is continuously filled with liquid metal and cooled down while going out of the mould. Here shrinkage occurs when the metal is cooled down, but no cavities are present as explained by Ashby, M. F. (1998)

A common subject in casting process is grain size. It is known that metals crystallize in the so called dendritic structures. Leading to big columnar formations in the exterior part of the casted piece, and smaller grains in the interior. Fine grain materials are harder than big grain ones (yield strength is increased by fine grains) this means that the big columnar grains are a source of weakness. To avoid this problem, there are different methods, like using inoculants added to the molten metal. These are small chemical catalyst added to the molten solution that helps crystallize in small grains (fine grain and small columnar regions). Other method is to apply powder metallurgy, where instead of a melting the metal, it is reduced to powder of small grain size. "Grain size is rarely controlled by cooling rate in real castings. Grain size is controlled by nucleation and mechanical process (such as agitation)" Edwards, L (1990) in the other hand, casting moulds have to be designed for the metal to flow easily in the interior, and a progressive solidification. Gasses have to be favoured to escape, and the section thickness of the mould has to be uniform (for a uniform diffusion of the heat)

In load bearing applications, it is as important the surface integrity of the component as the interior of the piece. It is worthy to take a look on how the grains grow from the outside to inside. As columnar grains grow, at the same time they push impurities ahead of them. In many cases this 'segregation' brings different concentration of impurities along the component, different composition and different properties (yield strength).

(b)

The function of a riser is to maintain the supply of molten metal to the cast while solidification, to prevent shrinkage and cavities in the mould. It is important for this that the solidification occurs first in the mould and then in the feeder.

In other words $t_{sr} > t_{sc}$ Solidification time in the riser must be greater than solidification time in the cast.

Solidification time is given by Chvorinov's rule, which stands for proportionality to the volume to area ratio of the casting.

$t_s = B\left(\frac{V}{A}\right)^n$ Where B is the mould constant, V the volume of the casting and A the surface area of the casting.

$t_{sr} > t_{sc}$

$B\left(\frac{V}{A}\right)^n > B\left(\frac{V}{A}\right)^n$ B and n are the same in the mould and raiser supposing that the material used and thickness is the same.

$\left(\frac{Vr}{Ar}\right) > \left(\frac{Vc}{Ac}\right)$ $\frac{\left[\pi\left(\frac{D}{2}\right)^2\right]H}{2\left[\pi\left(\frac{D}{2}\right)^2\right] + 2\pi\frac{D}{2}H} > \left(\frac{Vc}{Ac}\right)$ It is a specification that the ratio height to diameter of the casting is 1.5

$$\frac{\frac{\pi D^2}{4}(1.5D)}{2\left[\frac{\pi D^2}{4}\right] + \pi D(1.5D)} > \left(\frac{Vc}{Ac}\right) \quad \frac{1.5\pi D^3}{2\pi D^2 + 6\pi D^2} > \left(\frac{Vc}{Ac}\right) \quad \frac{\pi D^2(1.5D)}{\pi D^2(2+6)} > \left(\frac{Vc}{Ac}\right) \quad \frac{1.5D}{8} > \left(\frac{Vc}{Ac}\right)$$

Volume in the casting is $V = 0.1 * 0.5 * 0.25 = 0.125 m^3$

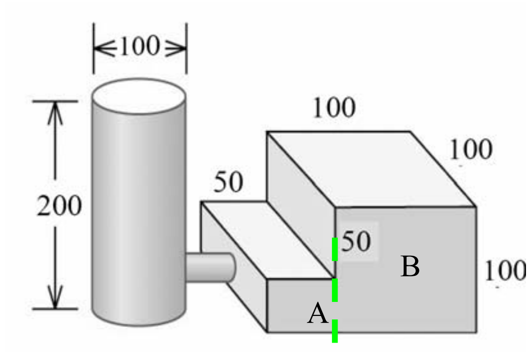
Area of the casting is $V = 2(0.1 * 0.25) + 2(0.1 * 0.5) + 2(0.25 * 0.5) = 0.4 m^2$

Substituting $\frac{1.5D}{8} > \left(\frac{0.125}{0.4}\right)$

We obtain that the **diameter** has to be at least **166mm**, and the **height** at least **249mm**.

(c)

As it has been explained before, the riser is intended to solidify after the casting itself $t_{sr} > t_{sc}$. Like this, the supply of molten metal through the raiser prevents the formation of cavities in the casting attributed to shrinkage. If the material shrinks, but more material arrives, there is no problem, no cavity. The solidification in the casting has to be also in the form that the last section to solidify must be the section closer to the raiser. For analyzing this, the casting is going to be divided into two sections (A and B):



Solidification time in **raiser**:

$$t_{rs} = B\left(\frac{V}{A}\right)^n = B\left(\frac{\pi r^2 h}{2(\pi r^2) + 2\pi r h}\right)^n = B\left(\frac{\pi 0.05^2 0.2}{2(\pi 0.05^2) + 2\pi 0.05 * 0.2}\right)^n = B(0.020)^n$$

Solidification time in **Section A**:

$$t_{sa} = B\left(\frac{V}{A}\right)^n = B\left(\frac{a*b*c}{2(a*b) + 4(b*c)}\right)^n = B\left(\frac{2.5*10^{-4}}{5*10^{-3} + 0.02}\right)^n = B(0.011)^n$$

Solidification time in **Section B**:

$$t_{sb} = B\left(\frac{V}{A}\right)^n = B\left(\frac{a*b*c}{2(a*b) + 4(b*c)}\right)^n = B\left(\frac{1*10^{-3}}{0.02 + 0.04}\right)^n = B(0.016)^n$$

Evaluation

$$trs > tsb > tsa$$

The raiser will not be effective, because solidification time in section A is shorter than in the raiser. This section will solidify first, and the riser will not be able to provide material to section B when this last section solidifies. One solution to this problem would be to relocate the raiser for supplying material to the casting through section B. it might be on the side or might be over section B. In this configuration will be effective because the solidification time of the riser is greater than the one of part B

Question 4

A carburizing process intends to spread a concentration of carbon through the section (profile) of a piece. This is done mainly exposing the surface to an atmosphere rich in carbon atoms. The carbon atoms are diffused into the material atomic structure, impeding the atomic planes from shearing (anti deformation) and compressing the surface (anti cracking). Carbon atoms are usually smaller than the atoms of the material, this is the reason why they can fit between the atomic structures of the surface and compress it**.** It is also worthy to mention that the alloys used for carburizing are still not saturated of carbon, so more atoms can be diffused.

Carburizing aims to improve the properties of the surface, not the interior of the piece. Edwards, L (1990) outlines the physical properties given by the martensite created by the high carbon content, “this volume increase creates a compressive residual stress” between the atoms, providing increased hardness.

(a)

Flick’s second law permits to evaluate the diffusion of carbon in the profile of the piece, and stands for:

$$\frac{cx - co}{cs - co} = 1 - erf\left(\frac{x}{2\sqrt{Dt}}\right)$$

Where Cx is the concentration at a depth x after a time t and erf(y) is a Gaussian error function usually gathered from tables.

D is the diffusion coefficient, and is given by the equation $D = D_o \exp\left(\frac{-Q}{RT}\right)$

(i)

Temp1 840ºC=1113ºK (ºC+273)

$D = D_o \exp\left(\frac{-Q}{RT}\right)$ $\ln D = \ln D_o - \frac{Q}{R} * \frac{1}{T}$ $\ln D = \ln 2.3*10^{-5} - \frac{1.45*10^5}{8.314} * \frac{1}{1113}$

D=2.6*10^{-12}

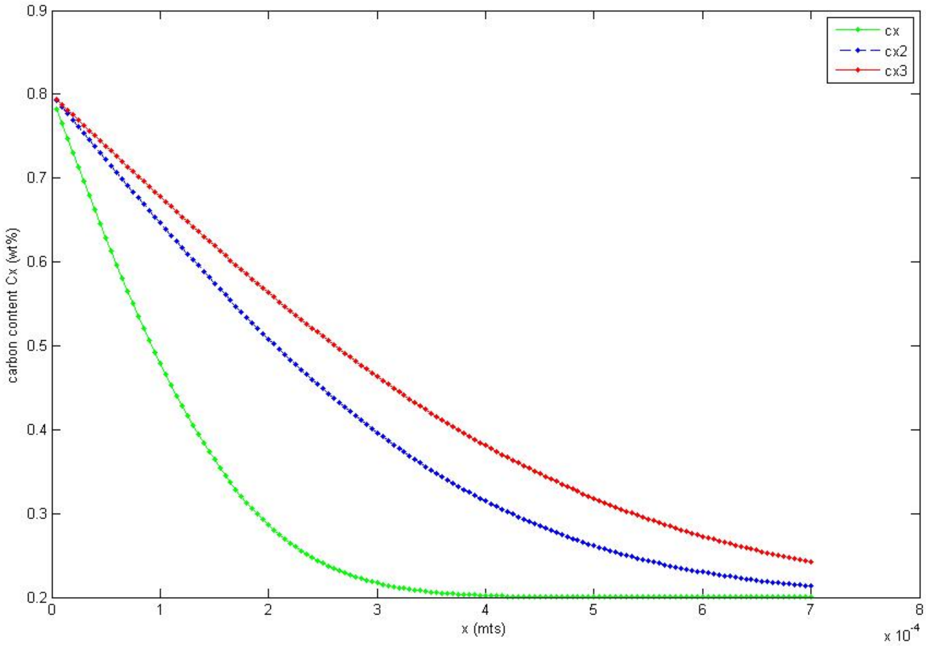
Temp2 880ºC=1153ºK (ºC+273)

$\ln D = \ln 2.3*10^{-5} - \frac{1.45*10^5}{8.314} * \frac{1}{1153}$ D=4.53*10^{-12}

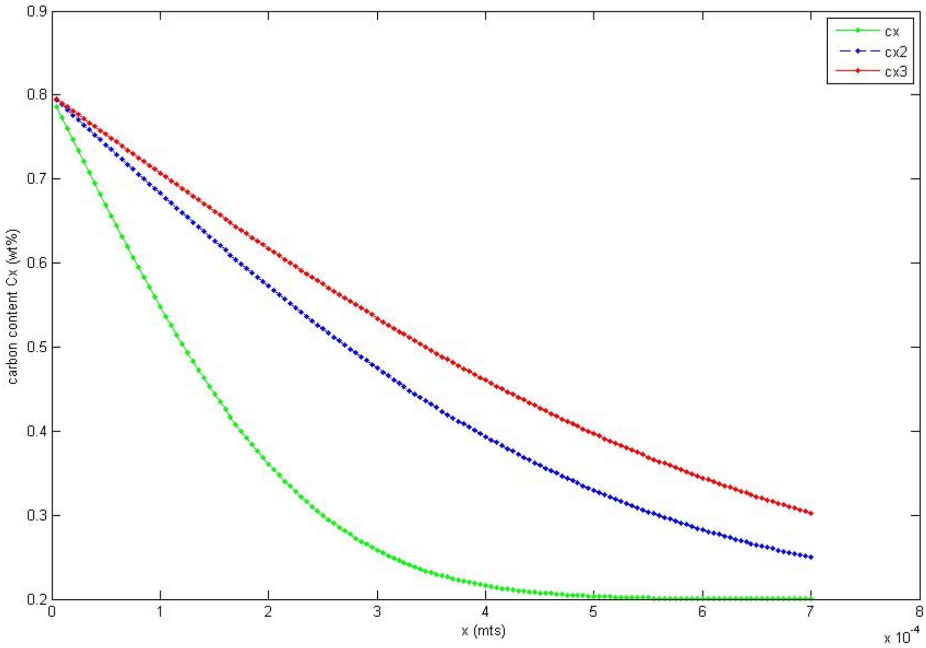
Temp3 930ºC=1203ºK (ºC+273)

$\ln D = \ln 2.3*10^{-5} - \frac{1.45*10^5}{8.314} * \frac{1}{1203}$ D=8.62*10^{-12}

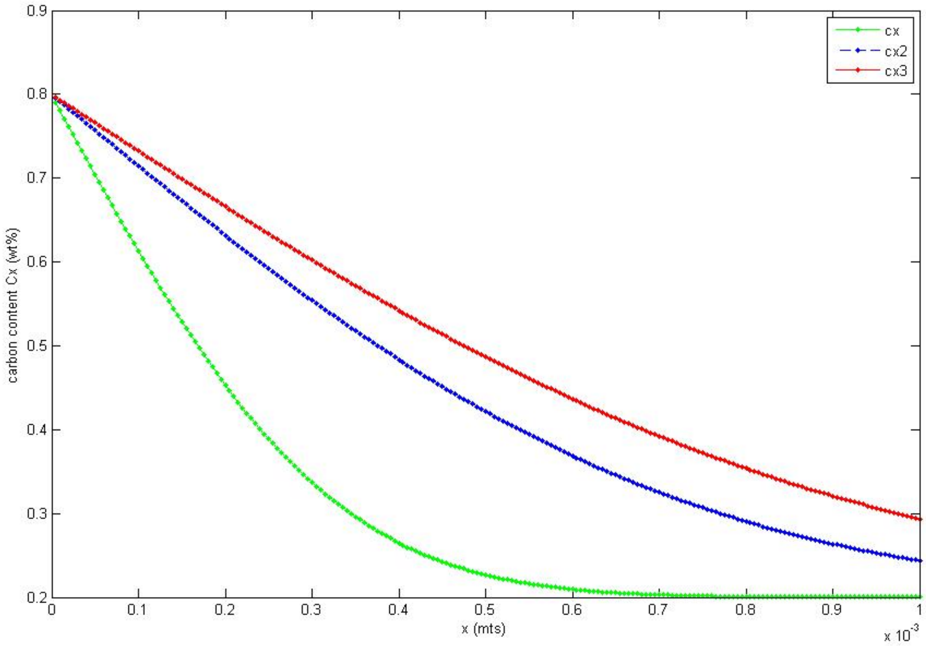
By using Flick’s second law and the diffusion coefficient, it can be simulated in a computer with the help of a software tool (necessary for the error function) the carbon profiles for the different conditions



Plot 1: Carburizing conditions A1=cx; A2=cx2; A3=cx3



Plot 2: Carburizing conditions B1=cx; B2=cx2; B3=cx3



Plot 3: Carburizing conditions C1=cx; C2=cx2; C3=cx3

(ii)

Starting from Flick's second law and taking a glance at the graphs before, the best conditions appears to be T=840ºC

$$\frac{cx-co}{cs-co}=1-erf\left(\frac{x}{2\sqrt{Dt}}\right) \quad \frac{0.3-0.2}{0.8-0.2}=1-erf\left(\frac{0.5*10^{-3}}{2\sqrt{2.6*10^{-12}t}}\right)$$

$$-0.833=-erf\left(\frac{0.5*10^{-3}}{2\sqrt{2.6*10^{-12}t}}\right)$$

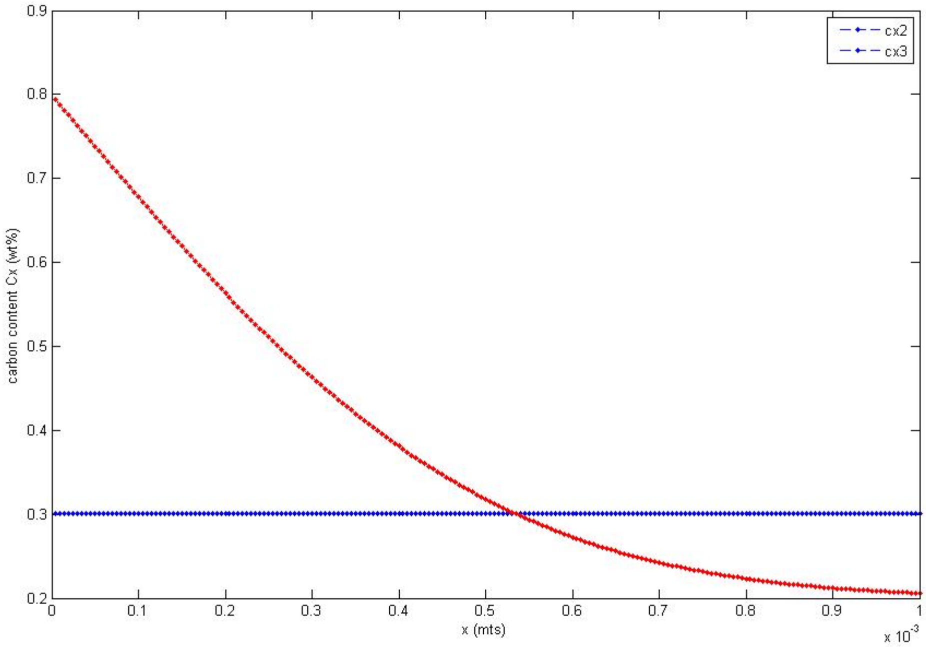
Deducing from the error table:

$$\frac{1-x}{1-0.975}=\frac{0.8427-0.833}{0.8427-0.832} \quad x=0.977$$

Substituting

$$0.977=\left(\frac{0.5*10^{-3}}{2\sqrt{2.6*10^{-12}t}}\right) \quad 0.977=\left(\frac{0.5*10^{-3}}{3.22*10^{-6}\sqrt{t}}\right) \quad \sqrt{t}=158.93 \quad t=25260seg$$

With a temperature of 840ºC there will be necessary 25260 seg. (7 hours) during a carburizing period of eight hours.



Plot 4: For T=840ºC and diffusion along 8 hours.

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