COE-C2004 - Materials Science and Engineering
2020-2021 Autumn II

Assignment 5, 29.11.2021

Task 1. Phase Transformation (15 points, Lecture9)

Figure 1 is the isothermal transformation diagram for a 0.45 wt% C iron-carbon alloy. List the microconstituent(s) present for the heat treatment labeled (a-c) on this diagram. Please explain your results.

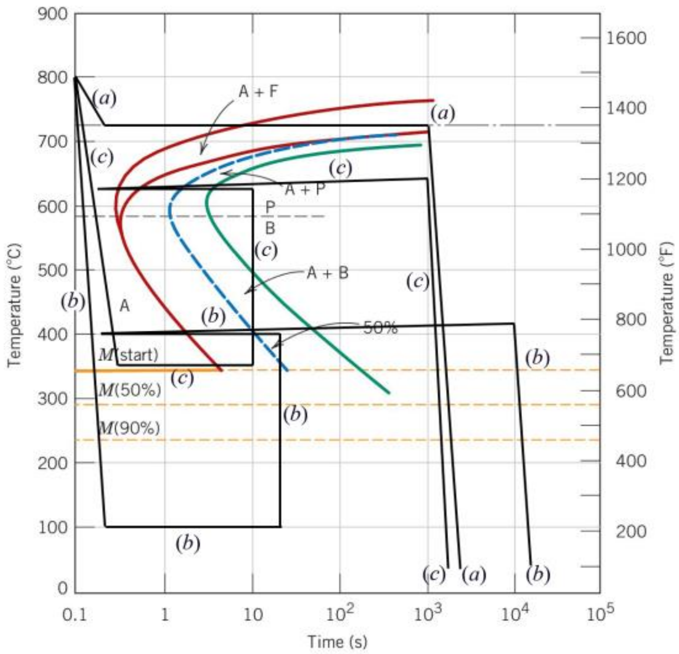

Figure 1. [1]

<u>Solutions:</u>

(a) proeutectoid ferrite and martensite. Upon cooling to 725 °C, the microstructure remains 100% austenite. While being held at this temperature for about 103 seconds, proeutectoid ferrite begins to form. As it is rapidly cooled to room temperature, the remaining austenite begins to transform to martensite at about 300 °C; all of this austenite will have transformed martensite at the end of this quench. Furthermore, there are no changes with the proeutectoid ferrite that has already formed; thus the final composition will consist of proeutectoid ferrite and martensite.

(b) tempered martensite. Upon rapid cooling to and while at 100 °C for 20 s, all of the austenite is converted to martensite. During the subsequent rapid heating to about 400 °C, no changes occur. While being held at 400 °C for about 104 s, all the martensite will transform to tempered martensite; and during the final cooling to about 100 °C no additional changes will occur. Thus the final microconstituent is tempered martensite.

(c) bainite, proeutectoid ferrite, and pearlite. There are no changes in the microstructure during the rapid cooling to 350 °C (i.e., only austenite will be present). As the alloy is held at that this temperature for about 10 seconds, approximately 25% of the alloy transforms to bainite. During the rapid heating to 625 °C there are no microstructural changes; however, while maintaining the alloy for about 103 seconds at this temperature, all the remaining austenite will transform to proeutectoid ferrite and pearlite. Since, by this time all of the austenite has transformed, no changes will occur during the final rapid cooling to room temperature. Thus, the final microstructure will consist of bainite, proeutectoid ferrite, and pearlite.

(Results 3 points + Explanation 2 points) × 3

Prof. Dr.-Ing. Junhe Lian junhe.lian@aalto.fi Tel.: +358 50 477 0765
Adv. Manufacturing and Materials | Department of Mechanical Engineering | School of Engineering | Aalto University
Mail address: P.O. Box 14200, FI-00076 Aalto, Finland; Visiting address: Puumiehenkuja 3, 02150 Espoo, Finland

Task 2. Process (52 points, Lecture9)

2.1 Explain what casting is? List at least four types of casting methods with their frequently used mold materials, general process, and applications. And make a comparison between different types of casting methods, using either tables or plots. (Hint: you can explain with methods, usages, results, examples, etc.).

Solutions:

Casting is a fabrication process whereby totally molten metal is poured into a mold cavity having the desired shape; upon solidification, the metal assumes the shape of the mold but experiences some shrinkage. Casting techniques are employed when (1) the finished shape is so large or complicated that any other method would be impractical, (2) a particular alloy is so low in ductility that forming by either hot or cold working would be difficult, and (3) in comparison to other fabrication processes, casting is the most economical. Furthermore, the final step in the refining of even ductile metals may involve a casting process. A number of different casting techniques are commonly employed, including sand, die, investment, lost foam, and continuous casting. The comparison between different types of casting methods is shown in the following table.

Type	Mold/Die	Method	Example/Application
Sand Casting	sand	A two-piece sand mold is formed by packing sand around a pattern that has the shape of the intended casting. Furthermore, a gating system is usually incorporated into the mold to expedite the flow of molten metal into the cavity and to minimize internal casting defects.	Sand casting is probably the most common method. Sand-cast parts include automotive cylinder blocks, fire hydrants, and large pipe fittings.
Die Casting	permanent steel mold or die	In die casting, the liquid metal is forced into a mold under pressure and at a relatively high velocity and allowed to solidify with the pressure maintained. A two-piece permanent steel mold or die is employed; when clamped together, the two pieces form the desired shape. When the metal has solidified completely, the die pieces are opened, and the cast piece is ejected. Rapid casting rates are possible, making this an inexpensive method; furthermore, a single set of dies may be used for thousands of castings.	This technique lends itself only to relatively small pieces and to alloys of zinc, aluminum, and magnesium, which have low melting temperatures.
Investment Casting (sometimes called lost-wax casting)	plaster of paris	The pattern is made from wax or plastic that has a low melting temperature. Around the pattern is poured a fluid slurry, which sets up to form a solid mold or investment; plaster of paris is usually used. The mold is then heated, such that the pattern melts and is burned out, leaving behind a mold cavity having the desired shape.	This technique is employed when high dimensional accuracy, reproduction of fine detail, and an excellent finish are required. For example, in jewelry and dental crowns and inlays. Also, blades for

			gas turbines and jet engine impellers are investment cast.
Lost Foam Casting	Sand	A variation of investment casting is lost foam (or expendable pattern) casting. Here the expendable pattern is a foam that can be formed by compressing polystyrene beads into the desired shape and then bonding them together by heating. Alternatively, pattern shapes can be cut from sheets and assembled with glue. Sand is then packed around the pattern to form the mold. As the molten metal is poured into the mold, it replaces the pattern, which vaporizes. The compacted sand remains in place, and, upon solidification, the metal assumes the shape of the mold. With lost foam casting, complex geometries and tight tolerances are possible. Furthermore, in comparison to sand casting, lost foam is a simpler, quicker, and less expensive process, and there are fewer environmental wastes.	Metal alloys that most commonly use this technique are cast irons and aluminum alloys; furthermore, applications include automobile engine blocks, cylinder heads, crankshafts, marine engine blocks, and electric motor frames.
Continuous Casting	stationary molds, materials depend on applications, e.g. 'open-pour' copper mold	At the conclusion of the extraction processes, many molten metals are solidified by casting into large ingot molds. The ingots are normally subjected to a primary hot-rolling operation, the product of which is a flat sheet or slab; these are more convenient shapes as starting points for subsequent secondary metal-forming operations (i.e., forging, extrusion, drawing). These casting and rolling steps may be combined by continuous casting (sometimes also termed strand casting) process. Using this technique, the refined and molten metal is cast directly into a continuous strand that may have either a rectangular or circular cross-section; solidification occurs in a water-cooled die having the desired cross-sectional geometry. The chemical composition and mechanical properties are more uniform throughout the cross-sections for continuous castings than for ingot-cast products. Furthermore, continuous casting is highly automated and more efficient.	This process is used most frequently to cast steel. Aluminum and copper are also continuously cast.

Definition of casting: 2 points;

(Type name 2 points + Mold materials 2 points + Process 2 points + Application 2 points) × 4

Prof. Dr.-Ing. Junhe Lian junhe.lian@aalto.fi Tel.: +358 50 477 0765
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2.2 Explain annealing and its various types of applications. Compare the differences between full annealing with quenching and tempering in terms of processing parameters, resulted microstructure and mechanical properties.

Solutions:

The term annealing refers to a heat treatment in which a material is exposed to an elevated temperature for an extended time period and then slowly cooled. Any annealing process consists of three stages: (1) heating to the desired temperature, (2) holding or "soaking" at that temperature, and (3) cooling, usually to room temperature. Time is an important parameter in these procedures. During heating and cooling, temperature gradients exist between the outside and interior portions of the piece; their magnitudes depend on the size and geometry of the piece. If the rate of temperature change is too great, temperature gradients and internal stresses may be induced that may lead to warping or even cracking. Also, the actual annealing time must be long enough to allow for any necessary transformation reactions. The annealing temperature is also an important consideration; annealing may be accelerated by increasing the temperature, because diffusional processes are normally involved.

Ordinarily, annealing is carried out to (1) relieve stresses; (2) increase softness, ductility, and toughness; and/or (3) produce a specific microstructure. A variety of annealing heat treatments are possible; they are characterized by the changes that are induced, which many times are microstructural and are responsible for the alteration of the mechanical properties.

The comparison of full annealing with quenching and tempering is shown in the following table.

Method	Processing parameter	Microstructure and Mechanical property
Full annealing	Annealing temperature: 50 °C above the A3 line (solvus line between the γ-phase region and α-γ-two-phase region) to form austenite for hypoeutectoid steel. Or, for hypereutectoid steel, 50 °C above the A1 line (eutectoid line) to form austenite and Fe_3C phases. Long annealing time to make sure the full phase transformation to form austenite microstructure. Followed with a slow cooling rate, i.e. furnace cooled.	The microstructural product of this anneal is coarse pearlite (in addition to any proeutectoid phase) that is relatively soft and ductile.
Quenching and tempering	Quenching from the full austenite region with a high cooling rate, normally water or oil cooling. Followed by tempering at a proper temperature below A1 temperature (eutectoid temperature), then cooling with proper rate, general air cooling.	The final microstructure is tempering martensite, with high strength and relatively low ductility.

Definition of annealing: 2 points; Applications of annealing: 2 points

(Processing parameter 3 points + Microstructure 2 points + Mechanical property 2 points) × 2

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Task 3. Inorganic Non-metallic Materials (33 points, Lecture10)

3.1 True or False

(1) For noncrystalline ceramics, plastic deformation occurs by the motion of dislocations.

(2) The coordination number of ionic ceramics is constrained by the relative sizes of the compound's component species.

(3) Consider the ZrO_2 crystal structure. The coordination number of Zr_{4+} ions is 8.

(4) Na_2O, CaO, Al_2O_3, and B_2O_3 are all oxides that may be found in silica-based glasses.

(5) With increasing temperature, the following is the correct phase transformation sequence for a glass: supercooled liquid, solid, and liquid.

(6) Consider the ideal barium titanate ($BaTiO_3$) structure, the coordination number of the Ba_{2+} ion in terms of surrounding Ti_{4+} ions is 8.

Solutions: (2 points × 6 = 12)

(1) False, For noncrystalline materials, plastic deformation does not occur by the motion of dislocations. Instead, some materials, e.g. noncrystalline ceramics, deform by viscous flow.

(2) True

(3) True

(4) True

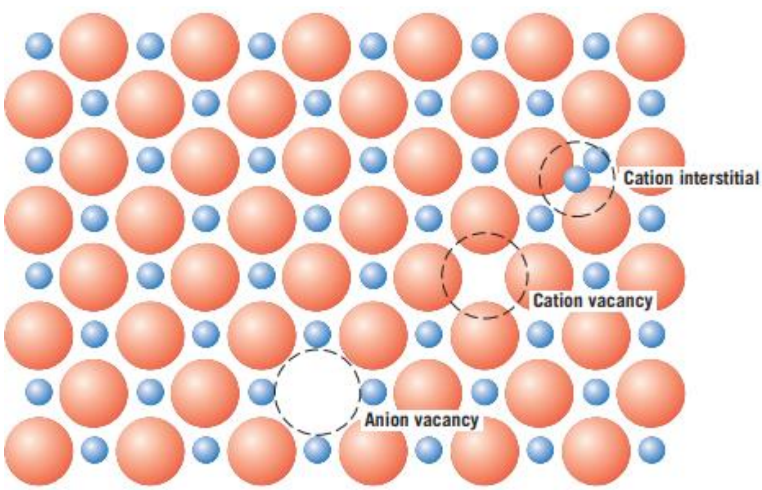
(5) False, With increasing temperature, the following is the correct phase transformation sequence for a glass: solid, supercooled liquid, and liquid.

(6) False, 12 Ti_{4+} ions surround each Ba_{2+} ion.

3.2 Name and plot seven kinds of ionic point defects that are found in ceramic compounds. (Please use figures and illustrations and make a proper citation of the figures if they are not created by you).

Solutions:

Defects in ionic ceramics: cation/anion vacancy, cation interstitial impurity, cation/anion substitutional impurity, Frenkel defect (a cation vacancy-cation interstitial pair), Shottky defect (a cation-anion vacancies pair).



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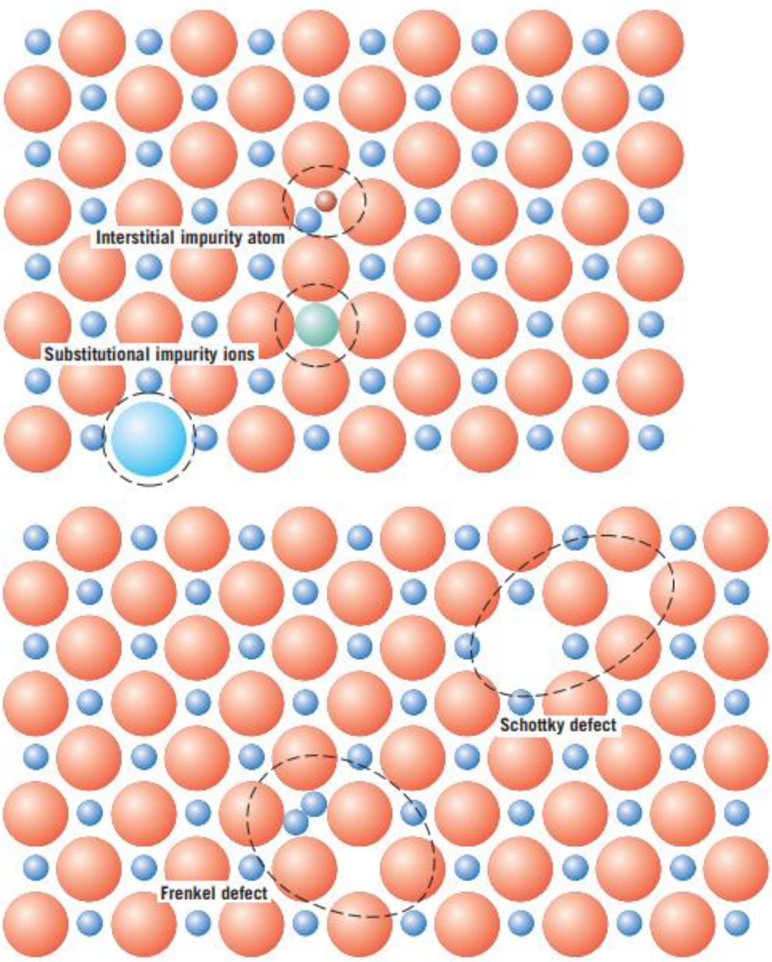

Figure 2 Schematic representations of defects in ceramics. [1]

(Name 1 point + figure 2 points) × 7

Reference

[1] W. D. Callister and D. G. Rethwisch, *Materials Science and Engineering: An Introduction, 8th Edition*, Wiley, 2009.

Due date: 18:00, 05.12.2021.

Contact: MyCourses 'General discussion' channel

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