Principles of heat treatment of steel pdf download full version download

The time temperature cycle for tempering is chosen so as to optimize strength and toughness. 39. The interior of the sample is cooled by conduction through the (hot) sample and hence experiences a lower cooling rate. 26. 17. 41. For hyper-eutectoid steels the heating is not done above Acm to avoid a continuous network of proeutectoid cementite along prior Austenite grain boundaries (presence of cementite along grain boundaries provides easy path for crack propagation). • To improve Toughness • To increase Hardness • To increase Ductility • To improve Machineability • To refine Grain Structure • To remove Residual Stresses • To improve Wear Resistance 3. PRINCIPLES OF HEAT TREATMENT – Fe – Carbon Diagram 5. the residual stresses develop in the sample. HEAT TREATMENT BULK SURFACE ANNEALING Full Annealing Recrystallization Annealing Stress Relief Annealing Spheroidization Annealing AUSTEMPERING THERMAL THERMO- CHEMICAL Flame Induction LASER Electron Beam Carburizing Nitriding Carbo-nitriding NORMALIZING HARDENING & TEMPERING MARTEMPERING 9. HARDENING ■ Thermal stresses during heating should be avoided. Internal stresses caused by rolling and rolling or forging are removed. Fine pearlite has a reasonably good hardness and ductility. In hyper-eutectoid steels normalizing done above Acm → due to faster cooling cementite does not form a continuous film along GB. The metal is heated to the range of 220- 300 degrees and cooled. 34. The sample is then air cooled to obtain Fine pearlite. In reality the microstructural changes which take place during tempering are very complex. Recovery Heating increased diffusion enhanced dislocation motion decrease in dislocation density by annihilation, formation of low-energy dislocation configurations relieves internal strain energy Some of the mechanisms of dislocation annihilation: vacancies slip plane Edge dislocation 21. Critical diameter (dc) is that diameter, which can be through hardened (i.e. we obtain 50% Martensite and 50% pearlite at the centre of the sample). Recrystallization After recovery grains can still be strained. 18 Effect of Cold Drawing on Yield strength & Ductility 19. Low carbon steels may harden through cold working.They can be heated to around 100 degrees below lower critical temp., soaked and allowed to cool in air. 44. 16. 12. Assistant professor, Department of Mechanical engineering, Kamaraj college of engineering and technology, Virudhunagar. ■ This will lead to local distortion and embrittlement of the tool due to the presence of untempered martensite. Tempering A sample with martensitic microstructure is hard but brittle. ■ To homogenize the structure which is dislocated due to cold forming & semi hot & Hot forgings Cold rolled Grain structure Annealed Grain structure 25. ■ Normalising. However, alloying gives two separate 'C-curves' for Pearlitic and Bainitic transformations (e.g. figure to the right). A material with a high hardenability can be cooled relatively slowly to produce 50% martensite (& 50% pearlite). In Austempering instead of quenching the sample, it is held at T1 for it to transform to bainite. 13. Through: • Change in Microstructure • Change in Chemistry or Composition 4. 10. Coarse Pearlite has low (↓) Hardness but high (↑) Ductility. This gives a good combination of strength and toughness. ■ To get the best microstructure and tool performance the quenching rate should be rapid. To minimize distortion, a slow quenching rate is recommended. Tempering is carried out just below the eutectoid temperature (heat → wait→ slow cool). A material with a high hardenability has the 'nose' of the CCT curve 'far' to the right (i.e. at higher times). Controlled Heating And Cooling of Metal to Change Its Properties and Performance. That is, one area may have more carbon than the area adjacent to it. Through:Change in microstructure. Annealing ■ Makes a metal as soft as possible ■ Hypoeutectoid steels (less than 0.83% carbon) are heated above upper critical temp., soaked and cooled slowly. NORMALIZING Refine grain structure prior to hardening To harden the steel slightly To reduce segregation in casting or forgings Purposes The sample is heat above A3 | Acm to complete Austenization. ■ In the case of high speed steel, the holding time will be shorter when the hardening temperature is over 1100°C (2000°F). The quenching process produces residual strains (thermal, phase transformation). How to increase hardenability? 33. ■ Two tempers are generally recommended for tool steel, except in the cases of large cross-sections, parts with complex geometries. Holding (soak) Time Temperature What is Heat Treating ? THANK YOU A1 A3 Acm T Wt% C 0.8 % 723C 910C Full Annealing Hardening Hardening 32. ■ Process Annealing. Stress Relief Annealing Annihilation of dislocations, polygonization Welding Differential cooling Machining and cold working Martensite formation Residual stresses → Heat below A1 → Recovery A1 T Wt% C 0.8 % 723C 910C Stress Relief Annealing Due to various processes like quenching (differential cooling of surface and interior), machining, phase transformations (like martensitic transformation), welding, etc. In both these processes Austenized steel is quenched above Ms (to a temp T1) for homogenization of temperature across the sample. 27. The driving force for this (microstructural) transformation is the reduction in interfacial energy. ■ If this is not possible, the material must be kept warm, ■ e.g. in a special "hot cabinet" awaiting tempering. 23 Recrystallization 24. ■ Spheroidising. The component is reheated and held at temperature for a period of time and cooled slowly. 29. Full Annealing The steel is heated above A3 (for hypo-eutectoid steels) & A1 (for hyper-eutectoid steels) → (hold) → then the steel is furnace cooled to obtain Coarse Pearlite. Jominy hardenability test Variation of hardness along a Jominy bar (schematic for eutectoid steel) Schematic of Jominy End Quench Test 40. The main purpose of the treatment is to increase the ductility of the sample. Martempering Austempering T1 46. To achieve this the sample is heated below A1 and held there for sufficient time for recrystallization to be completed. Restoration to state before cold-work by heat- treatment: Recovery and Recrystallization, followed by grain growth. ■ In every heat treatment, the heating process is named ramping. Steels are heated above upper critical temp., soaked and cooled in air. ■ This, in turn, will result in a hardness increase of up to 1–2 HRC 42. These cornpositional differences affect the way in which the steel will respond to heat treatment. WHAT IS HEAT TREATING? A1 A3 Acm T Wt% C 0.8 % 723C 910C Full Annealing Full Annealing A microstructure with coarse pearlite (i.e. pearlite having high interlamellar spacing) is endowed with such properties. HARDENING Heat above A3 | Acm → Austenization → Quench (higher than critical cooling rate) The sample is heated above A3 | Acm to cause Austenization. Such a material can be through hardened easily. 18. For heat treatment of steels, the first resource to become familiar with is the iron–cementite equilibrium phase diagram, which shows the equilibrium phases in iron–carbon alloys for a given temperature and composition.From: Comprehensive Materials Processing, 2014 1. Tempering ■ The material should be tempered immediately after quenching to avoid cracks . Strain Hardening Due to Cold Drawing New yield strength yi higher than initial yield strength, y0. The annealing is carried out just below A1 , wherein 'recovery*' processes are active (Annihilation of dislocations, polygonization). E.g. tool steel has a as quenched hardness of Rc65, which is tempered to get a hardness of Rc45-55. A1 A3 Acm T Wt% C 0.8 % 723C 910C Spheroidization Recrystallization Annealing Stress Relief Annealing Full Annealing Ranges of temperature for Annealing, Normalizing and Spheroidization treatment are carried out for hypo- and hyper-eutectoid steels. Maternsite being a metastable phase decomposes to ferrite and cementite on heating (providing thermal activation). This implies that to continue deformation the material needs to be recrystallized (wherein strain free grains replace the 'cold worked grains'). A: austenite B: bainite M: martensite P: pearlite 8. Below "critical deformation", recrystallization does not occur. The sample is then quenched at a cooling rate higher than the critical cooling rate (i.e. to avoid the nose of the CCT diagram). 2. Through hardening of the sample Schematic showing variation in cooling rate from surface to interior leading to different microstructures 38. ■ Stress relieving. This is followed by tempering. The transformation to Martensite is usually not complete and the sample will have some retained Austenite. A material with low hardenability may have a higher surface hardness compared to another sample with higher hardenability. ■ A second tempering gives the material optimum toughness at the chosen hardness level 43. Quenching media ■ Brine (water and salt solution) ■ Water ■ Oil ■ Air ■ Turn off furnace 36. 22 Recrystallization –effect of Cold work on temperature Recrystallization temperature: temperature at which process is complete in one hour. In Martempering the steel is then quenched and the entire sample transforms simultaneously to martensite. Recovery, Recrystallization, and Grain Growth Plastic deformation increases dislocation density + changes grain size distribution Therefore, stored strain energy (dislocation strain fields + grain distortions) External stress removed: most dislocations, grain distortions and associated strain energy retained. 14. Long time heating leads cementite plates to form cementite spheroids. 17 Strain Hardening due to Cold Drawing Yield strength + hardness increased due to strain hardening, but ductility decreased (material becomes more brittle). The list of uses of normalizing are listed below. ■ Quenching should be stopped at a temperature of 50– 70°C (120–160°F) and tempering should be done at once. Hardenability should not be confused with the ability to obtain high hardness. Strained grains replaced upon heating by strain-free grains with low density of dislocations. Typical hardness test survey made along a diameter of a quenched cylinder The surface of is affected by the quenching medium and experiences the best possible cooling rate. In hypo-eutectoid steels normalizing is done 50C above the annealing temperature. ■ The most commonly used are about -80°C (-110°F) ■ and -196°C (-320°F). The Martensite produced is hard and brittle and tempering operation usually follows hardening. This implies that different parts of the same sample follow different cooling curves on a CCT diagram and give rise to different microstructures. Cementite ORF Ferrite BCC Martensite BCT Temper)(Ce)()(' 3 45. TTT diagram of low alloy steel (0.42% C, 0.78% Mn, 1.79% Ni, 0.80% Cr, 0.33% Mo) U.S.S. Carilloy Steels, United States Steel Corporation, Pittsburgh, 1948) Hardenability of plain carbon steel can increased by alloying with most elements (it is to be noted that this is an added advantage as alloying is usually done to improve other properties). FullTTT Diagram The complete TTT diagram for an iron- carbon alloy of eutectoid composition. ■ Hypereutecoid (above 0.83%) are heated above lower critical temp., soaked and allowed to cool slowly. Controlled Heating And Cooling of Metal to Change Its Properties and Performance. High carbon steels may be annealed just below the lower critical temp. ■ If the holding time is prolonged, microstructural problems like grain growth can arise. Hence after quenching the sample (or component) is tempered. Because of characteristics inherent in cast steel, the normalizing treatment is more frequently applied to ingots prior to working, and to steel castings and forgings prior to hardening. 28. AUSTEMPERING CHAIN LINK PLATE-C45 SEAT BELT BUCKLE - CK 55 BAINITE Principle of Austempering Heat Treatment Process 47. 20. 23. Banded Microstructure Normalised Microstructure 30. ZING The process might be more accurately described as a homogenizing or grain-refining treatment. to improve machinability. Heat Treating Hardening Steels by Quenching and Tempering • Time-Temperature Transformation Diagram: 35 35. PRINCIPLES OF HEAT TREATMENT – Fe – Carbon Diagram FERRITE- B C C AUSTENITE- F C C MARTENSITE- B C T 6. The cooling rate is faster than annealing giving a smaller grain structure. Spheroidization Annealing A1 A3 Acm T Wt% C 0.8 % 723C 910C Spheroidization This is a very specific heat treatment given to high carbon steel requiring extensive machining prior to final hardening & tempering. Recrystallization decreases as %CW is increased. Heat-treating temperature ranges for plain-carbon steels 11. Recrystallization is slower in alloys 22. ■ This can be achieved by using sub-zero treatment after ■ Quenching. Within any piece of steel, the composition is usually not uniform throughout. At 723 degrees, the BCC ferrite changes into Austenite with a FCC structure. This implies that the 'nose' of the Bainitic transformation has to be avoided to get complete Martensite on quenching. Like stress relief annealing the treatment is done just below A1. TTT Diagrams 7. Typically 1/3 to 1/2 of melting temperature (can be as high as 0.7 Tm in some alloys). Quenching Treatment: 37. To aid machinability ,to eliminate the nonconformities present in microstructure such as banding – Normalising is done. Residual stress can lead to undesirable effects like warpage of the component. Change in Chemistry or composition Why Heat Treat? ■ Tempering colours are an indicator of temperature on polished metals. Colours range from yellow to brown to violet and blue. The ramping for hardening should be made in different steps ■ preheating temperatures are 600–650°C (1100– ■ 1200°F) and 800–850°C (1450–1560°F). Tempering ■ To remove some of the brittleness from hardened steels, tempering is used. Recrystallization: nucleation and growth of new grains Driving force: difference in internal energy between strained and unstrained Grain growth short-range diffusion Extent of recrystallization depends on temperature and time. Morphology of Pearlite (a) coarse pearlite (b) fine pearlite 3000X (a) (b) 15. Recrystallization Annealing Heat below A1 → Sufficient time → Recrystallization A1 A3 Acm T Wt% C 0.8 % 723C 910C Recrystallization Annealing During any cold working operation (say cold rolling), the material becomes harder (due to work hardening), but loses its ductility. Austenite Pearlite Pearlite + Bainite Bainite Martensite 100 200 300 400 600 500 800 723 0.1 1 10 102 103 104 Eutectoid temperature Ms Mf t (s) → T→ + Fe3C MARTEMPERING & AUSTEMPERING These processes are developed to avoid residual stresses generated in quenching. ■ Therefore the requirement of maximum dimensional stability in service has an implied demand for very low or no retained austenite content. Problems in Heat Treatment 48. A1 A3 Acm T Wt% C 0.8 % 723C 910C Normalization Normalization 31. Hardening ■ Medium and High carbon steels (0.4 – 1.2%) can be heated until red hot and then quenched in water producing a very hard and brittle metal. ■ SUB-ZERO TREATMENT ■ Retained austenite in a tool can transform into martensite during service. Hence, recrystallization annealing is used as an intermediate step in (cold) deformation processing. This gives to a varying hardness from centre to circumference. Reason strain hardening. HEATTREATMENT-I Prepared By Mr.P.Senthamaraikannan, M.E., (Ph.D).

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