1. INTRODUCTION

2. OVERVIEW OF INDUSTRIAL APPLICATIONS OF INDUCTION HEATING

   2.1. Heat treatment by induction
       2.1.1. The basics of metallurgy and principles of heat treatment
       2.1.1.1. Crystalline structure of elements and critical temperatures
       2.1.1.2. Equilibrium phase transformation diagram
       2.1.1.3. Time-Temperature Transformation (TTT) diagram and Continuous Cooling Transformation (CCT) diagram
       2.1.1.4. Steel’s trace elements and alloying elements
       2.1.1.5. Hardenability
       2.1.1.6. Effect of heat intensity (heating rate) on induction heat treatment results
       2.1.1.7. Effect of prior microstructure of steel
       2.1.1.8. Induction heat treatment of cast irons
       2.1.2. Hardening
       2.1.3. Tempering and stress relieving
       2.1.4. Normalizing
       2.1.5. Annealing
       2.1.6. Spherodizing
       2.1.7. Sintering
       2.1.8. Heat treating of light metals

   2.2. Induction mass heating
       2.2.1. Bar, rod and billet reheating
       2.2.2. Slug heating for semisolid forming
       2.2.3. Tube, pipe and vessel heating
       2.2.4. Wire, rod and cable heating
       2.2.5. Slab, plate, rectangular bar and bloom heating
       2.2.6. Induction heating of strips, thin slabs, plates and sheets
       2.2.7. Coating

   2.3. Special applications of induction heating
       2.3.1. Joining, friction welding, brazing, bonding and soldering
       2.3.2. Shrink fitting
       2.3.3. Banding
       2.3.4. Motor rotor heating (lamination bluing and bond breaking)
       2.3.5. Seam annealing
       2.3.6. Food industry
       2.3.7. Papermaking
       2.3.8. Wool and wood processing
       2.3.9. Chemical industry
       2.3.10. Automotive sealing
       2.3.11. Cap sealing
       2.3.12. Die heating
       2.3.13. Miscellaneous

   2.4. Induction melting
       2.4.1. Induction channel-type furnaces
       2.4.2. Induction crucible-type (coreless) furnaces
       2.4.3. Induction vacuum furnace

   2.5. Induction welding

3. THEORETICAL BACKGROUND

   3.1. Basic electromagnetic phenomena in induction heating
       3.1.1. Electromagnetic properties of metals
       3.1.2. “Skin” effect
       3.1.3. Electromagnetic proximity effect
       3.1.4. Electromagnetic slot effect
       3.1.5. Electromagnetic ring effect
       3.1.6. Electromagnetic force
       3.1.7. Introduction to electromagnetic end and edge effects

   3.2. Basic thermal phenomena in induction heating
       3.2.1. Thermal properties of the materials
       3.2.1.1. Thermal conductivity
       3.2.1.2. Heat capacity and specific heat
       3.2.2. Three modes of heat transfer; conduction, convection, and radiation
       3.2.2.1. Thermal conduction
       3.2.2.2. Convection mode of heat transfer
       3.2.2.3. Radiation mode of heat transfer

   3.3. Estimation of the required power and dynamics of induction heating
       3.3.1. Estimation of the required power for induction heating
       3.3.2. Intricacies of the dynamics of induction heating
3.4. Advanced induction principles and mathematical modeling
  3.4.1. Mathematical modeling of the electromagnetic field
  3.4.2. Mathematical modeling of the thermal processes
  3.4.3. Numerical computation of the process
    3.4.3.1. Traditional methods of calculation
    3.4.3.2. Finite difference method
    3.4.3.3. Finite element method
    3.4.3.4. Mutual impedance method
    3.4.3.5. Boundary element method
    3.4.3.6. Coupling of the electromagnetic and thermal problems

4. TEMPERATURE MEASUREMENT
  4.1. Color indicators
  4.2. Contact-type sensors (thermocouples)
  4.3. Infrared radiation theory and non-contact sensors (pyrometers)
    4.3.1. Infrared radiation theory
    4.3.2. Bandpass single detector IR thermometers
    4.3.3. Two color, two detector ratio thermometers
    4.3.4. Sources of measurement error in non-contact temperature measurement and some solutions
    4.3.5. Fiber optic IR thermometer systems
    4.3.6. Thermography
    4.3.7. Specifics of IR temperature measurement in induction heat treating and mass heating of metals
    4.3.8. Care and maintenance of infrared thermometers

5. HEAT TREATMENT BY INDUCTION
  5.1. Machine design for induction surface and through hardening
    5.1.1. Heating modes
      5.1.1.1. Static heating mode
      5.1.1.2. Scan heating mode
      5.1.1.3. Progressive heating mode
      5.1.1.4. Pulse heating mode
    5.1.2. Frequency choice and power density
    5.1.3. Duration of heat for surface hardening
    5.1.4. Inductor styles
      5.1.4.1. Scan inductors
      5.1.4.2. Progressive inductors
      5.1.4.3. Single-shot inductors
      5.1.4.4. Special inductors
      5.1.4.5. Specifics of designing of inductors for heating interior surfaces
      5.1.4.6. Induction proximity heating of flat and plane surfaces
      5.1.4.7. Inductors with inserts
      5.1.4.8. Coupling gaps
      5.1.4.9. “Profiled” coils
      5.1.4.10. Inductors for heating of irregular shapes
    5.1.5. “Striping” phenomena, barber pole effect and snakeskin (soft-spotting) phenomenon
    5.1.6. Quenching and spray quench design for inductors
    5.1.7. Cooling of induction coils and tubing selection
    5.1.8. Inductor mounting styles
    5.1.9. Accessory equipment and work handling
      5.1.9.1. Robots and gantries
      5.1.9.2. Hoppers and magazines
      5.1.9.3. Conveyors
      5.1.9.4. Rotary tables
  5.2. Induction heat treatment of crankshafts, camshafts and axle shafts
    5.2.1. Crankshaft heat treatment by induction
    5.2.2. Induction hardening of camshafts
    5.2.3. Hardening shafts
  5.3. Residual stresses and cracking in induction heat treating
  5.4. Gear hardening
    5.4.1. Materials selection and required gear conditions prior to heat treatment
    5.4.2. Overview of hardness patterns
    5.4.3. Coil designs and heat modes
      5.4.3.1. “Tooth-by-tooth” and “gap-by-gap” inductors
      5.4.3.2. Gear spin hardening (encircling inductors)
    5.4.4. Lightening holes (weight reduction holes)
    5.4.5. Powdered metal gears
    5.4.6. TSH technology for gear hardening
  5.5. Tempering
5.5.1. Self-tempering (“slack quenching”)
5.5.2. Induction tempering and its features
5.6. Induction heat treating of powder metals
5.7. Electromagnetic end and edge effects in induction hardening and tempering
5.8. Longitudinal and transverse holes, key ways, grooves, various oriented hollow areas
5.9. Magnetic flux control techniques: magnetic shields, magnetic shunts, and magnetic flux concentrators (intensifiers)
  5.9.1. Electromagnetic shields
  5.9.2. Magnetic shunts
  5.9.3. Magnetic flux concentrators (flux intensifiers)
    5.9.3.1. Physics of the magnetic flux concentration
    5.9.3.2. Design and application features
    5.9.3.3. Selection of flux concentrator materials
    5.9.3.4. Advantages and drawbacks of using magnetic flux concentrators
    5.9.3.5. Case studies
5.10. Coil fabrication, storage and maintenance
5.11. Basics of metallographic sample preparation and modern equipment for microstructural analysis
  5.11.1. Introduction
  5.11.2. Theoretical background of sample preparation
  5.11.3. Stages of sample preparation, basic guidelines, and rules of thumb
    5.11.3.1. Sectioning
    5.11.3.2. Mounting
    5.11.3.3. Grinding
    5.11.3.4. Polishing
    5.11.3.5. Cleaning
    5.11.3.6. Etching
  5.11.4. Basic review of hardness testing technique and apparatus
  5.11.5. Microscopes and principles of microscopic analysis

6. SPECIAL APPLICATIONS OF INDUCTION HEATING

6.1. Joining applications
  6.1.1. Brazing and soldering by induction
    6.1.1.1. Overview of metal joining principles
    6.1.1.2. Types of joints
    6.1.1.3. Size and shape factors
    6.1.1.4. Frequency selection
    6.1.1.5. Types of inductors and coil design features
    6.1.1.6. Overview of filler materials and flux selection
    6.1.1.7. Fixturing and handling
    6.1.1.8. Summary
  6.1.2. Bonding
  6.1.3. Cap sealing
  6.1.4. Shrink fitting
6.2. Induction melt-out (lost-core technology)
6.3. Motor rotor heating
6.4. Die heating

7. INDUCTION MASS HEATING

7.1. Applications, design approaches and fundamental principles of induction mass heating prior to metal hot working
7.2. In-line induction heating of long cylindrical bars and rods
  7.2.1. Electro-thermal nature of inline induction heating
  7.2.2. Longitudinal and transverse cracks
  7.2.3. Transient processes and “nose-to-tail” temperature profiles
  7.2.4. Energy efficiency of inline bar and rod heaters.
7.3. Billet heating
  7.3.1. Induction heating of steel billets
  7.3.2. Induction heating of non-ferrous billets
7.4. Bar/Billet/Rod end heater
7.5. Slug heating for semi-solid processing
  7.5.1. Nature of semi-solid processing and basic phenomena
  7.5.2. Shortcomings of mathematical modeling induction heating for semi-solid casting
  7.5.3. Technological aspects of commercial induction heating systems for SSM forming
7.6. Intricacies of induction wire/cable/rope heating
  7.6.1. Specifics of design criteria and coil arrangements
  7.6.2. Energy efficiency
    7.6.2.1. Frequency selection
    7.6.2.2. Ferrous and nonferrous wires
    7.6.2.3. The factor of system geometry
  7.6.3. Commercial induction wire, cable, and rope heaters
7.7. Tube and pipe heating
  7.7.1. Specifics of induction heating of tubular products
  7.7.2. In-line induction heating of tubes and pipes and their applications
  7.7.3. Selective heating of tubular products and case studies of typical applications

7.8. Slab, plate, bloom and rectangular bar heating
  7.8.1. General remarks
  7.8.2. Longitudinal electromagnetic end effect of a rectangular workpiece
    7.8.2.1. Nonmagnetic slab
    7.8.2.2. Magnetic slab
  7.8.3. Electromagnetic transverse edge effect
    7.8.3.1. Parameters related to transverse edge effect of a nonmagnetic slab
    7.8.3.2. Specifics of transverse edge effect of a magnetic slab
    7.8.3.3. Dynamics of transverse edge effect during heating cycle
  7.8.4. Design concepts of induction slab heating systems and case studies of commercial installations
    7.8.4.1. Static heating
    7.8.4.2. Inline continuous heating
    7.8.4.3. Oscillating heating

7.9. In-line induction heating of strip, sheet, plate, thin slab and transfer bar
  7.9.1. Strip coating processes
    7.9.1.1. Metallic coating of strips (galvanizing, galvaluming, galvannealing, tinning)
    7.9.1.2. Nonmetallic coatings
  7.9.2. Coil design approaches for heating strips, plates, sheets and thin slabs
    7.9.2.1. Longitudinal flux inductor (solenoid coil)
    7.9.2.2. Transverse flux induction heater (TFIH)
    7.9.2.3. Travelling wave induction heater (TWIH)
    7.9.2.4. Channel-type coils
    7.9.2.5. C-core inductors
    7.9.2.6. Doorless technology for strip processing lines

7.10. Material handling
  7.10.1. Billet handling
  7.10.2. Handling of long bars, rods and tubes
  7.10.3. Slab, plate and transfer bar handling

8. POWER SUPPLIES FOR MODERN INDUCTION HEATING

8.1. Power-Frequency combinations
8.2. Elements of power electronics
  8.2.1. Inductors
  8.2.2. Capacitors
  8.2.3. Vacuum tubes and power semiconductors
    8.2.3.1. SCR or thyristor
    8.2.3.2. Diode or rectifier
    8.2.3.3. Transistors
    8.2.3.4. Vacuum tube oscillators
    8.2.3.5. Power-frequency applications of semiconductors and vacuum tubes
8.3. Types of induction heating power supplies
  8.3.1. Rectifier or converter section
  8.3.2. Inverter section
    8.3.2.1. Full-bridge inverter
    8.3.2.2. Half-bridge inverter
    8.3.2.3. Voltage-fed inverters with simple series load
    8.3.2.4. Voltage-fed inverters with series connection to a parallel load
    8.3.2.5. Current-fed inverters
    8.3.2.6. Single switch inverter
  8.3.3. Operational considerations
    8.3.3.1. Initial cost
    8.3.3.2. Operating cost
    8.3.3.3. Reliability and maintainability
    8.3.3.4. Flexibility
8.4. Load matching
8.5. Medium and high-frequency transformers for heat treating and mass heating
8.6. Special considerations for power supplies
8.7. Special considerations for induction brazing, soldering, and bonding
8.8. Special considerations for induction heating power supplies in mass heating applications
8.9. Special considerations for induction heating power supplies in strip processing applications
8.10. Comparison of solid-state power supplies and vacuum tube oscillators
8.11. The importance of having a good power factor
8.12. Harmonics and their reduction
  8.12.1. Nature and cause of harmonics
  8.12.2. Solutions to power factor and harmonic problems
8.13. Power supply cooling
   8.13.1. Water quality
   8.13.2. Cooling water flow rate
   8.13.3. Cooling water re-circulating systems
   8.13.4. Common water-cooling problems

   8.14.1. Prelude to discussion of process control and monitoring
      8.14.1.2. Specifics of control and monitoring of induction mass heating
   8.14.2. Meters and meter circuits
   8.14.3. Features of control / monitoring strategies for induction heat treating vs. induction mass heating
   8.14.4. Basic principles of feedback and control algorithms
   8.14.5. Energy monitoring
   8.14.6. Advanced monitoring and “signature” analysis
   8.14.7. Protective devices and safety principles