PRACTICAL WORKBOOK

MM- 304: Heat Treatment of Materials

Name_____
Roll No_____
Batch_____
Year_____
Department_____

Department of Metallurgical Engineering

NED University of Engineering and Technology

Karachi-75270, Pakistan

Practical Workbook

MM- 304: HEAT TREATMENT OF MATERIALS

PREPARED BY

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(Assistant Professor, MYD)

This is to certify that this practical book contains_____ pages.

Approved by:

Chairman, MYD

Department of Metallurgical Engineering

NED University of Engineering and Technology

Karachi-75270, Pakistan

CERTIFICATE

It is certified that Mr. / Ms. _____ student of class **SE** Batch, bearing Roll No. MY _____ has completed his / her course work in the subject of **Heat Treatment of Materials (MM-304)** as prescribed and approved by the Board of Review of the Metallurgical Engineering Department.

His/her performance is reflected by the performance rubrics of his/her practical workbook. This overall performance of the student is going to address the assigned learning attribute.

_____

Course Teacher

Table of Contents

MM-304 HEAT TREATMENT

Experiment No. 1

Aim of Experiment

To guide the Safety Measures related to Heat Treatment Equipment, and Furnaces.

Table 1: showing different types of furnaces with respect to heat treatment operations

Types of furnace	Heat treatment operations							
	Annealing	Normalizing	Tempering	Carborizing	Solution Treatment	Nitriding	Austempering	Hardening
Soaking fit furnace	Yes	Yes						
Batch in and out furnace	Yes	Yes		Yes	Yes			
Box furnace	Yes	Yes	Yes	Yes				Yes
Carbon bottom furnace	Yes	Yes	Yes	Yes	Yes			Yes
Pit furnace	Yes	yes	Yes	Yes	Yes	Yes		Yes
Bell and hood furnace			Yes		Yes	yes		Yes
Elevating Hearth furnace			Yes					Yes
Integral Quench furnace				Yes	Yes	Yes		Yes
Tip up Furnace			Yes					Yes
Rolary Hearth furnace			Yes		Yes		Yes	Yes
Conveyo Hearth furnace			yes	yes		yes	yes	Yes

General Equipment of Heat Treatment

There are various important equipments and parts used in heat treatment furnaces for example circulating fans, burner's ports quenching tanks, agitators, sacks, chimney, stock feed blocks etc. etc. Some general equipment and parts in various heat treatment furnaces are listed as follows.

Heat Treatment Furnaces

According to the fuel used, furnaces for heat treatment can be solid fuel fired. Liquid fuel fired, gas fired and electrically heated types.

Furnace Refractory

Fire bricks are chiefly used for building and relining of heat treatment furnaces, electric furnace linning is patched with special refractory bricks or with plain fire bricks shaped to the configuration desired. Similarly, ceramic wool blanket may be used for electrically heated furnaces.

Temperature Control Equipment

1. Manometric thermometers
2. Thermocouple
3. Optical and Radiation Pyrometers
4. Temperature recorder with profile scale

Burner and its types

1. One Stage, Large capacity burners
2. Two stage, Large capacity burners
3. Low pressure burners
4. Slot type burners
5. Turbulent flame type burners
6. Separate gas and air type burners

Door and its types

Furnace door should be tight, light and durable and heat proof. Some common types of heat-treating furnaces door are as follows

1. Hinged door
2. Mechanically operated door
3. Door with reinforced insulating cement
4. Solid type door
5. Open type door
6. Door with undercut frame
7. Rigid door with structural members
8. Structural door with mounted furnaces car
9. Split door
10. Chain type door

Heat Saving Equipments

Fuel represents very important fraction of total heat treatment operation. For this reason, heat saving equipment must be given consideration. Some example of heat saving equipment are listed below.

1. Recuperator
2. Regenerator
3. Waste heat boiler
4. Pre heaters for feed stock

Damper and its types

1. Dampers with water cooled frames for high temperature
2. Sectional dampers for medium temperature
3. Ribbed stack damper for low temperature
4. Air operated dampers
5. Stack type dampers

Questionnaires

Q.1: What is the purpose of solenoid valve and safety shut-off valve in heat treatment furnaces?

Q.2: What is purpose of governor and gas regulator in Heat treatment furnaces?

Q.3: What is the purpose of the Recuperator or Regenerator in the heat treatment furnaces?

Q.4: What is thermocouple? Also tell its purpose & commonly used types in heat treatment furnaces?

Q.5: What is the purpose of burners, dampers and chimney in the heat treatment furnaces?

_____

_____

_____

_____

Q.6: What do you mean by heat treatment furnace automation?

_____

_____

_____

_____

Experiment No. 2

Aim of Experiment

Operate the heat treatment furnace for normalizing operation to refine the as-rolled microstructure for AISI 1045.

Apparatus

As rolled samples (bar or plate), Muffle-type furnaces, Tweezers, and safety gloves.

Theory

Normalizing is a heat treatment in which material is austenized at temperatures (A3 or > Acm) for a particular soaking time followed by cooling in still or slightly agitated air. It is an important treatment to refine the microstructure and to improve the machinability of steels, because air cooling is an effective process to eliminate GB carbide network. All of standard low, medium and high produces harder and strengthened steel than annealed steel.

NORMALIZING CYCLE

Procedure

_____

_____

_____

_____

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_____

_____

_____

_____

_____

_____

Observation

Sample #	Hardness(HRC)		Microstructure	
	As received	Solution annealed	As received	Solution annealed
1				
2				

Micrograph

(a) As received

(b) Normalized

Conclusion

Questionnaires

Q1: Normalizing is sometimes considered as post heat treatment why?

Q2: Why normalized microstructure is harder than annealed microstructure?

Q3: Cite any three differences between normalizing and annealing.

Q4: How normalizing improves machinability?

Q5: Why cold worked components give better surface finish?

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Psychomotor Domain Assessment Rubric-Level P3					
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Remarks	
Instructor's Signature with Date:	

Experiment No. 3

Aim of Experiment

Manipulate the effects of various quenching mediums on AISI 1045 and study its microstructure.

Apparatus

Muffle type furnace, safety gloves, Tweezer, AISI 1045 samples, Quenchant (oil, water, and bine) and quenching pots and carbon steel samples.

Theory

Quenching is a technique of very drastic cooling of heated component in a medium in such a way that upon quenching excessive distortion, quench cracking and any undesirable transformation products must be avoided and eliminated. There are various types of quenching mediums are available each of which has their own capacity to extract the heat energy from the heated component upon quenching, this capacity or quench severity depends on the properties of quenchants like viscosity, specific heat, latent heat of vaporization, thermal conductivity, volatile content etc. therefore each quenchant effects on the microstructure, transformation and cooling rates in different way. The most commonly used quenching mediums are water, oil and brine solution.

Procedure

Observation

- Samples dimensions =_____ mm

Sample #	**Hardness (HRC)**			
	As received	Brine quenched	Oil quenched	Water quenched
1				
2				

Conclusion

_____

_____

_____

Questionnaires

Q.1: What is the most common quenchant why?

Q.2: What is synthetic quenchant? Also give any two examples.

Q.3: Calculate M_s temperature for AISI 5135 7 AISI 4140.

Q.4: Explain why oil is considered to be a slower quenching medium than water?

Q.5: Define the term “Transformation stresses”?

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Experiment No. 4

Aim of Experiment

Practice and study the effects of tempering temperatures on hardness of Carbon steel.

Theory

Tempering temperature lowers hardness marginally. However, this marginal loss is adequately compensated by advantages gained by relieving of residual (internal) stresses, ductility and toughness restoration and transformation of retained austenite. Therefore, higher the tempering temperature., the more is the restored ductility and toughness. However, due attention should be paid towards hardness, because this is the aim of hardening treatment. Selection of proper tempering temperatures offer the optimum mechanical properties.

Tempering Cycle

Procedure

_____

_____

_____

_____

_____

_____

_____

_____

Observation

Sample dimension = _____mm

Sample material =_____ mm

Sample #	Hardness(HRC)			
	As received	Tempered _____ .C	Tempered _____ .C	Tempered _____ .C
1				
2				
3				

Conclusion

_____

_____

_____

_____

_____

Questionnaires

Q.1What is auto tempering?

_____

_____

_____

Q.2 How secondary hardening occurs in steel?

_____

_____

_____

Q.3 What is temper brittleness? Give its remedy.

_____

_____

_____

Q.4 What is LAVES phase?

_____

_____

_____

Q.5 What is C(epsilon)-carbide?Give its lattices structure,formula.

_____

_____

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Remarks	
Instructor's Signature with Date:	

Experiment No. 5

Aim of Experiment
Operate Under Supervision the heat treatment furnace for bainite formation in carbon steel.

Apparatus
High Carbon steel samples, salt bath, muffle type furnace, Tweezer, safety gloves.

Theory
Process in which a ferrous alloy is isothermally transformed from unstable austenite to bainite structure at a temperature below that of pearlite formation (under the nose region). Process consists of heating the work piece within the austenizing range usually (790^{o}C to 915^{o}C), followed by quenching in a bath maintained at a constant temperature usually in the range of (260^{o}C to 400^{o}C) then cooling to room temperature completes the process. Remember there is quite difference between austempering and conventional quenching and tempering.

Procedure

_____

_____

_____

_____

_____

_____

_____

_____

_____

Aus-tempering cycle

Observation

Sample #	Hardness		Microstructure	
	As Received	Austempered	As Received	Austempered
1				
2				

Micrograph

(a) As Received (b) Austempered

Conclusion

_____

_____

_____

_____

_____

Questionnaires

Q.1: What is Patenting Treatment?

Q.2: Difference between the morphologies of upper and lower bainite?

Q.3: Difference blue brittleness of H_2 embrittlement

Q.4: What will be the Microstructure of modified austempering treatment?

Q.5 Give few advantages of austempering?

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Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

Experiment No. 6

Aim of Experiment
Manipulate and perform Solution Annealing Cycle for Austenitic SS.

Apparatus
Austenitic SS samples, Muffle type furnace, Quenchant (oil and water), Quenching pot, Tweezer, Safety gloves.

Theory
Since austenitic SS have solubility limit of carbon about 0.05% at 800C and raise upto 0.5% at 1100C.Therefore solution annealing between 1050-1150C will take all carbon into solution by rapid cooling .However slow cooling or reheating within the range 550 degree-800C will led to rejection of carbon as cr23c6 even at very low carbon (<0.05%C).This carbide can have very adverse effect on the mechanical, properties, corrosion resistance, and weldability of austenitic SS. Therefore there are several techniques to reduce or eliminates the formation of this cr23c6 carbide, among them solution annealing is most viable technique to solve this problem.

Solution Annealing Cycle

Procedure

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

Observation

Sample #	Hardness(HRC)		Microstructure	
	As received	Solution annealed	As received	Solution annealed
1				
2				

Micrograph

(a) As received

(b) Solution annealed

Conclusion

_____

_____

_____

_____

Questionnaires

Q.1: What is role of $Cr_{23}C_6$ in austenitic SS?

Q.2: What is stabilization and sensitization?

Q.3: What do you mean by annealing texture?

Q.4: Why austenitic SS are non-magnetic in nature?

Q.5: How solution annealing helps in increasing the corrosion resistance of austenitic SS?

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Remarks	
Instructor's Signature with Date:	

Experiment No. 7

Aim of Experiment

Operate the heat treatment furnace to perform the age hardening effects on Al-Si alloy.

Apparatus

AL-Si alloy samples, Quenching pot, quenchant (water), muffle type furnace, Tweezer, Safety gloves.

Theory

Process of age hardening or precipitation hardening is quite suitable for non-ferrous metals and their alloys. The very basic need of this treatment is that the alloy must have solvus line in their constitutional diagram (that is, the solubility limit should decrease with their decreasing temperature). This process consists of two steps (Solution Treatment & Aging). During the first age hardening treatment procedure the alloy is first solution treated at high temperature and then cooled rapidly by quenching into water or some other coolong medium. The rapid cooling suppresses the separation of the second- phase so that the alloy exists at the low temperature in an unstable supersaturated state.

In the second type supersaturated solution undergoes microstructural changes that the second phase formation starts by the precipitation phenomenon either at room temperature or at some higher temperatures. The exact temperature for aging can be determined by two factors one is time for appreciable reaction and second is properties of interest.

Solution Treatment & Age Haredening Cycle

Procedure

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

Observation

SAMPLE #	**Hardness(HRC)**		**Microstructure**	
	As received	Age hardened	As received	Age hardened
1				
2				

Micrograph

(a) As received (b) Age hardened

Conclusion

Questionnaires

Q.1: What is meant by solvus line?

Q.2: Name few important commercial nonferrous alloys which are age hardened?

Q.3: What are GP zones explain briefly?

Q.4: Why hardening effect is reduced during overaging?

Q.5: Briefly coherent lattice theory?

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Experiment No. 8

Aim of Experiment
Manipulate and study the hardenability of steel via Jominy End Quench Test.

Apparatus
Jominy End Quench apparatus , carbon steel samples , Graph paper , Jominy specimen (as per ASTM Standard) , Quenchant and Muffle type furnace , tweezers , safety Gloves.

Theory
Hardenability is quantitative measure of depth not a material's property. It is susceptibility of steel of harder upon quenching and is related to depth and distribution of hardness. Hardenability of steels is reflected by its hardness throughout its cross-section while avoiding drastic quenching hardenability and hardness should be clearly distinguished.
There are some factors which affects the hardenability of steel:
Alloying content and their distribution in alloy, increasing alloy additions increase hardenability (high alpha' phase formed even at slow cooling rates), austenitic grain size, increasing grain size will increase hardenability and fine grained steel show low hardenability. Carbon content, increasing carbon content increasing hardenability but in case of hypereutectoid steel hardenability decreases because of undissolved carbides. Other factors are Hardenability assessment criteria (test), quenching media, Specimen Size, and Geometry.

Procedure

_____

_____

_____

Observation

Hardness(HRC)						
Distance from quench end(mm/inches)						

Specimen dimension =

Specimen material =

Critical Diameter (Do)= _____mm/inches

Graph b/w hardness vs. distance

Results

Hardenability (in term of ideal critical diameter)= D1=_____mm/inches

Questionnaires

Q1: Differentiate b/w hardness and hardenability.

Q2: Define the term “quench severity” also give formula for its calculation.

Q3: Why hardenability improves by coarsening of austenitic grain size?

Q4: Differentiate among the critical diameter, ideal critical diameter and base diameter.

Q5: What are factors that affect hardenability?

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Laboratory Session No._____ Date: _____

Psychomotor Domain Assessment Rubric-Level P3					
Skill Sets	Extent of Achievement				
	0	1	2	3	4
Equipment Identification Sensory skill to ***identify*** equipment and/or its component for a lab work.	Not able to identify the equipment.	--	--	--	Able to identify equipment as well as its components.
Equipment Use Sensory skills to ***demonstrate*** the use of the equipment for the lab work.	Doesn't demonstrate the use of equipment.	Slightly demonstrates the use of equipment.	Somewhat demonstrates the use of equipment.	Moderately demon strates the use of equipment.	Fully demonstrates the use of equipment.
Procedural Skills ***Displays*** skills to act upon sequence of steps in lab work.	Not able to either learn or perform lab work procedure.	Able to slightly understand lab work procedure and perform lab work.	Able to somewhat understand lab work procedure and perform lab work.	Able to moderately understand lab work procedure and perform lab work.	Able to fully understand lab work procedure and perform lab work.
Response Ability to ***imitate*** the lab work on his/her own.	Not able to imitate the lab work.	Able to slightly imitate the lab work.	Able to somewhat imitate the lab work.	Able to moderately imitate the lab work.	Able to fully imitate the lab work.
Observation's Use ***Displays*** skills to use the observations from lab work for experimental verifications and illustrations.	Not able to use the observations from lab work for experimental verifications and illustrations.	Slightly able to use the observations from lab work for experimental verifications and illustrations.	Somewhat able to use the observations from lab work for experimental verifications and illustrations.	Moderately able to use the observations from lab work for experimental verifications and illustrations.	Fully able to use the observations from lab work for experimental verifications and illustrations.
Safety Adherence Adherence to ***safety*** procedures.	Doesn't adhere to safety procedures.	Slightly adheres to safety procedures.	Somewhat adheres to safety procedures.	Moderately adheres to safety procedures.	Fully adheres to safety procedures.
Equipment Handling ***Equipment care*** during the use.	Doesn't handle equipment with required care.	Rarely handles equipment with required care.	Occasionally handles equipment with required care.	Often handles equipment with required care.	Handles equipment with required care.
Group Work ***Contributes*** in a group based lab work.	Doesn't participate and contribute.	Slightly participates and contributes.	Somewhat participates and contributes.	Moderately participates and contributes.	Fully participates and contributes.

Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	

Experiment No. 9

Aim of Experiment
Manipulate to design and perform annealing cycle for copper to reduce the strain hardening effect.

Apparatus:
High copper samples, Muffle furnace, Tweezer, safety gloves.

Theory:
In case of pure copper thru heat treatment process which is adopted is annealing. The purpose of annealing is to achieve the original ductility and softness in cold worked copper. Pure copper is annealed at about 600degree C. After holding at this temperature for some time, copper is quenched in cold water. Annealing temperature of copper is higher than is recrystallization temperature. Water quenching removes scale formed and clean the surface of copper. Annealing above 600degreee C does not have any significant effect on the copper except that grain coarsening occurs. Grain coarsening is undesirable since it reduce ductility.
Other heat treatment of copper and copper alloys include homogenizing, stress relieving and age hardening or precipitation hardening.

Annealing Cycle For Copper

Procedure

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

Observation

Sample dimensions = _____mm

Sample composition = _____

Sample #	Hardness (HRC)	
	As received	Annealed
1		
2		
3		

Conclusion

_____

_____

_____

_____

Questionnaires

Q:1 What is season cracking? Give heat treatment for its remedy?

Q:2 Why most Cu-Zn alloys are not age hard enable?

Q:3 Differentiate between brasses and bronzes?

Q:4 What will be the structure of Annealed copper ?

Q:5 Why Copper is most suitable for automobile radiators?NED University of Engineering & Techno

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Weighted CLO (Psychomotor Score)	
Remarks	
Instructor's Signature with Date:	