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UNIVERSITY OF TECHNOLOGY

EXAM

COURSE	**Manufacturing processes**
COURSE CODE	**MPR034**
STUDY YEAR/PERIOD	**2024/2025 Study Period 1**
EXAMINER	**Peter Krajnik**
DATE OF THE EXAM	**2024-10-29**
EXAM AIDS	**No aids are allowed**
COURSE RESPONSIBLE	**Peter Krajnik** **031-772 1311** **peter.krajnik@chalmers.se**
OTHER INFORMATION	**The exam gives 6 credits and is assessed against 100 points in total with the following grading:** • **Fail – 0-39 points** • **3 (Passed) – 40-59 points** • **4 (Passed with credit) – 60-79 points** • **5 (Passed with distinction) – 80-100 points** • **There are 30 exam questions (100 points)** • **Extra 4 bonus questions (max. 10 points)**

SPECIFIC INFORMATION

This exam combines:

- **True or false / multi-choice questions (20 points)**. These questions give 1-2 point(s) each; please provide a table that includes each question number and the letter/s of the answer which is/are true **(you can use the table below)**. There are several statements for each question: at least one statement is true, but potentially more statements could be true (independently from the phrasing of the question). True answers give positive points, wrong answers give negative points. Thus, if you mark as true an answer that was false, you will lose points.
- **Free-response / short-answer questions (80 points)**. Please, provide clear answers and, when appropriate, use simple schematic illustrations to better explain your answers. Preferably answers should be single sentence statements. Please limit your answers to one page per question.

ANSWER TABLE FOR TRUE OR FALSE / MULTI-CHOICE QUESTIONS

Question	***Points***	***Letter/s indicating true answers***
1	***2***	***c. d.***
5	***2***	***b. d.***
9	***2***	***a. b.***
12	***2***	***a. c.***
15	***2***	***b. d.***
17	***2***	***a. d.***
20	***2***	***a. c.***
26	***2***	***b. d.***
27	***2***	***a. c.***
30	***2***	***a. b.***
TOTAL	***20***	
BONUS		
32	***2***	***a. b.***
34	***2***	***a. b.***

(General aspects of manufacturing processes) *[6p]*

1. Which of the following statement(s) about sustainable manufacturing is/are true? *[2p]*
   a. Sustainable manufacturing is primarily concerned with reducing labor costs rather than focusing on environmental or social impacts.
   b. Sustainable manufacturing has no impact on a company's supply chain, as it only concerns the internal production processes.
   c. Sustainable manufacturing emphasizes a cradle-to-cradle approach, which considers the entire lifecycle of a product, from raw material extraction to end-of-life disposal or recycling.
   d. Sustainable manufacturing practices often include efforts to reduce greenhouse gas emissions and water usage in manufacturing processes.

2. Explain the difference between a direct- and an inverse process control problem in manufacturing. Provide a simple example for each to illustrate your explanation. *[4p]*

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Direct vs. inverse (control) problem

- The **DIRECT problem** is like following a recipe to make a cake.
- *You have all the ingredients (like flour, sugar, eggs) and specific instructions (mix, bake at 175°C for 30 minutes). If you follow the recipe, you know what steps to take to make the cake, and you can predict the outcome: a cake!*
- **Key idea**: In a direct problem, you know the steps (input) and you predict or observe the result (output).
- **Example in manufacturing**: You know the energy settings and the beam path (input), and you want to find out what surface will result (output).

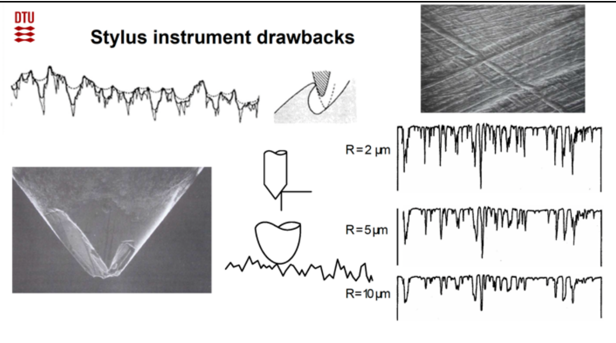
- The **INVERSE problem** is like being given a cake with a certain taste and texture, and your task is to figure out the recipe that made it.
- *You see the final cake and have to work backwards to figure out what ingredients were used, in what quantities, and what steps were taken to make it.*
- **Key idea**: In an inverse problem, you know the desired result (output), but you have to figure out the right steps (input) to get there.
- **Example from manufacturing**: You know what surface you want (output), and you need to determine the exact energy settings, beam path, and other parameters (input) to achieve it.

(Manufactured surfaces) *[6p]*

3. Define the Sa surface roughness parameter and explain its formula. *[2p]*

• *Sa* → arithmetic mean of the ordinates, within a definition area *A* (scale-limited surface) $$Sa = \frac{1}{A}\iint_A |z(x,y)|\, dx\, dy$$
The Sa surface roughness parameter, known as the arithmetic mean of the ordinates, represents the average absolute deviation of the surface heights from the mean plane over a defined area. In the formula above: • A is the area of the surface being measured, • z(x,y) is the height of the surface at any given point (x,y) relative to the mean plane.

4. What are the drawbacks of a stylus instrument? *[2p]*

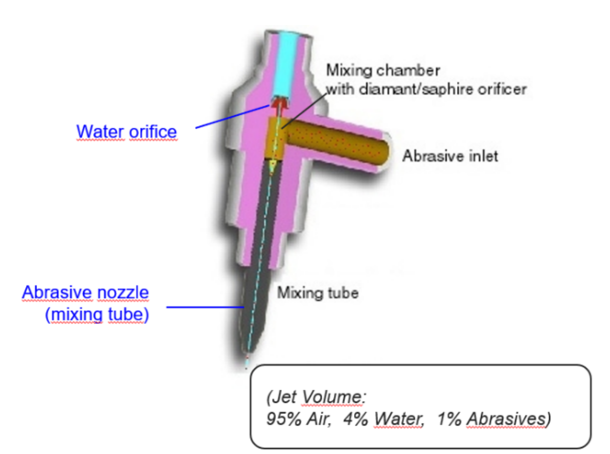


- Can be used with a wide variety of surfaces, but limited to hard surfaces
- Very time consuming when taking areal measurements

5. Which of the following statement(s) about the surface functional correlation of the 2nd kind is/are true? *[2p]*
   a. The functional correlation of the 2nd kind only focuses on the manufacturing process and has no relation to the final component's performance.
   b. The functional correlation of the 2nd kind refers to how surface topographies can change the interactions with the surfaces.
   c. The functional correlation of the 2nd kind refers to how the manufacturing process alters the surface roughness but does not affect the functional properties of the component.
   d. Design engineers use the functional correlation of the 2nd kind to optimize surface characteristics like roughness to improve the performance of components.

(Non-conventional processes) *[12p]*

6. Explain how the abrasive waterjet is formed and what it consists of *[4p]*

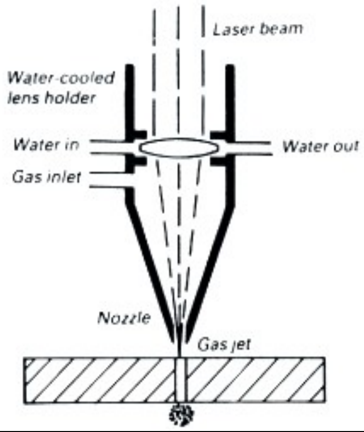


Takes place in the “cutting head”:
Pressurized water is let out from the orifice into the mixing chamber creating the pure WJ at high speed. In the mixing chamber there is an abrasive inlet where abrasive particles are “sucked in” by the partial vacuum created by the WJ. The abrasive particles are then accelerated by the jet (in fact the droplets hitting particles) and further accelerated and focused in the mixing tube (nozzle). What exits consist to the main part of air entrained in the mixing chamber, abrasive particles and water droplets.

7. Some special machines for AWJ cutting use ’taper compensation’. What is that and why is that of interest? *[2p]*

The cut kerf has a taper (angle) so that it is shallower at the bottom. To compensate for this some machine has the possibility to "tilt" (angle) the cutting head as to make a straight (perpendicular) cut kerf.

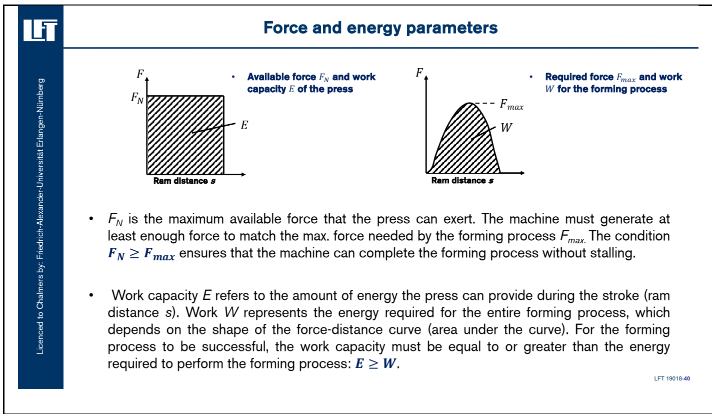
8. Laser cutting: How can oxygen be used in laser cutting? For what material is it mainly used and for what reason (explain)? Also explain (make sketch) how the oxygen is applied. *[6p]*

	In laser cutting there is a need for gas to remove the cut (molten) material (can be air, O_2, inert gases) Oxygen provides additional energy in Fe-cutting (mild steel for instance) by an exothermal reaction: $Fe + ½O_2 \rightarrow FeO$ + heat. This reaction requires quite a lot of heat to be activated/to start (which the laser has), but as it provides additional heat (see chem reaction), the possible cutting speed is increased. The gas is provided through the center of the cutting head outlet

(Metal-cutting and metal-forming machines) *[7p]*

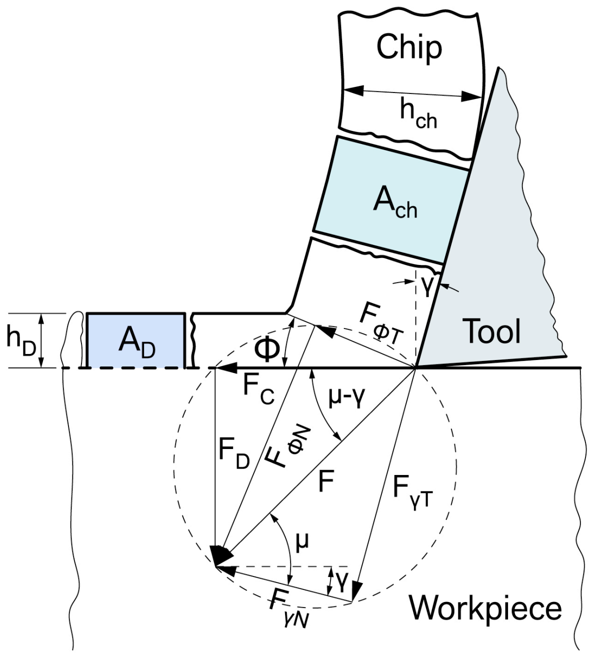
9. Which of the following statement(s) about the structural loop of a machine tool is/are true? *[2p]*
   a. The structural loop includes both structural elements like frames and beds, as well as machine components like guideways and drives.
   b. Compliance in any part of the structural loop can affect the precision of the tool relative to the workpiece.
   c. Increasing stiffness in the structural loop will always improve machine performance, regardless of other factors.
   d. The structural loop refers only to the mechanical components responsible for driving the machine.

10. Explain the conditions necessary for a press to complete a forming process. In your answer, explain the terms nominal force, maximum force, work capacity, and required work, and describe how these parameters ensure the process can be carried out. *[5p]*

	Nominal force (F_N) is the maximum force that the press is capable of exerting (i.e., available force) For a press to complete a forming process, two conditions must be met: • **Force condition**: The press's nominal force F_N must be equal to or greater than the maximum force Fmax required by the process. • **Energy condition**: The press's work capacity E must be equal to or greater than the required work W for the process. This ensures the press can apply sufficient energy over the entire stroke distance.

(Machining processes and machinability) [16p]

11. Have a look at the schematic illustration of the Merchant's force diagram below:



- Which are the two forces that can be measured in an orthogonal cutting setup? [2p]

Cutting force: Fc & **Thrust force**: F_D

- What is the resultant force in the above diagram? What is the easiest way to determine the resultant force? [2p]

Resultant force: F; $F = \sqrt{F_c{}^2 + F_D{}^2}$ (easiest determined via measured Fc and F_D)

- How do you estimate the coefficient of friction (ratio of the frictional force resisting the motion of the chip over the tool rake face to the normal force) using the nomenclature in the above illustration? *[2p]*

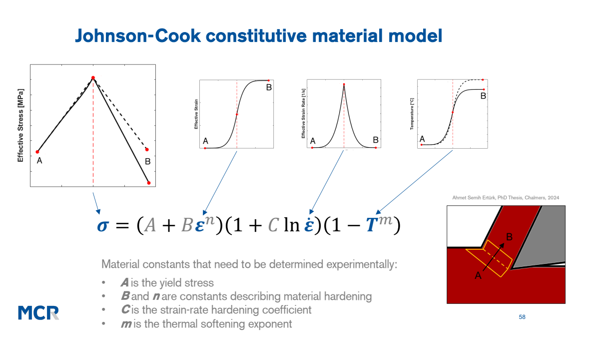
The coefficient of friction between the tool and the chip is $\frac{F_{\gamma T}}{F_{\gamma T}}$

- What is ϕ in the illustration above? What happens in the plane denoted by ϕ? *[2p]*

ϕ is the **shear angle**, and the plane at this angle is the **shear plane**, where the material shears (plastically deforms) and flows as a chip.

12. Which of the following statement(s) about strain-hardening in machining is/are true? *[2p]*
    a. Strain-hardening causes the shear stress to vary throughout the plastic zone.
    b. Strain-hardening assumes a constant shear stress across the entire plastic zone.
    c. Strain-hardening leads to a tensile stress near the cutting edge.
    d. Strain-hardening does not apply to metal cutting as the string theory only describes how the strings propagate through the space.

13. Explain how the Johnson-Cook model helps to predict the behavior of work materials during machining. Why is it important to consider both strain rate and temperature when using this model? *[3p]*



For machining simulations to be accurate, it's essential to identify the Johnson-Cook parameters (A, B, n, C, m).

By considering both strain rate and temperature, the model provides a more accurate prediction of how materials will respond under specific machining conditions.

NOTE: It is not expected to write the model with the equation, but to demonstrate your understanding that higher temperatures soften the work material, and that material stress depends on strain/strain rate.

14. What type of chip formation is more common when machining ISO-N materials? How about ISO-S and ISO-K? Explain shortly the reasons for such chip formation! *[3p] HINT: You need to choose between flow, lamellar, segmented, or discontinuous chip.*

- <u>Continuous</u> (flow) chips in ISO-N materials: Due to their ductility and softness, non-ferrous metals deform smoothly to form continuous flow chips.

- Segmented chips in ISO-S materials: Heat resistant superalloys form segmented chips because their high strength and low thermal conductivity cause intense localized shear and poor heat dissipation.
- Discontinuous chips in ISO-K materials: Cast irons produce discontinuous (short chips) because their low ductility causes the material to fracture rather than plastically deform during machining.

(Metalworking fluids) *[6p]*

15. Which of the following statement(s) about thermal aspects of machining is/are true? *[2p]*

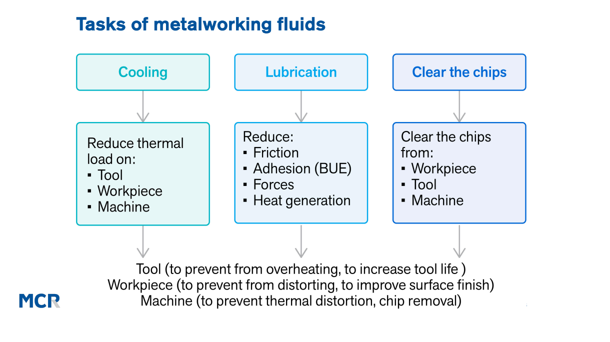
    a. In machining, all mechanical work to remove material is converted into friction, therefore tool wear is the main concern of the process.

    b. The mechanical work required to remove material and frictional work in machining are mainly converted into heat, hence reducing friction by lubrication and cooling are of outmost importance.

    c. Water-based coolants act efficiently to increase the temperature both of the workpiece and the tool making work material softer and easier to machine.

    d. One of the main heat sources in machining is on the tool rake face, over which the chip is formed. Reducing friction by lubrication can result in less heat generated and hence lower temperatures.

16. What basic conditions are necessary to facilitate dry machining? Which alternative methods to flood cooling do you know *[4p]*



In dry machining we need to compensate for the missing tasks of metalworking fluids (see left):

- No cooling and lubrication: Use tools that can withstand high temperatures (often with advanced coatings), ensure the machine can handle increased temperatures from hot chips, and prevent thermal damage to the workpiece (e.g., by adjusting cutting parameters)
- Chip evacuation: Ensure effective chip clearing mechanisms are in place
- Alternatives: For example, minimum-quantity lubrication (MQL) or cryogenic machining

(Grinding processes) *[10p]*

17. Why are thermal loads higher in grinding than in machining processes like milling? *[2p]*

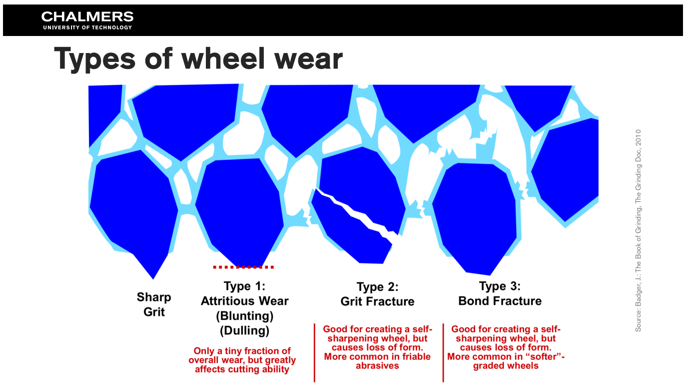
    a. The higher thermal loads in grinding are primarily due to the geometrically undefined cutting edges, which lead to more plowing and rubbing, generating additional heat.

b. The chips produced in grinding are larger than those in milling, which increases the thermal loads.

c. The rake angle of the abrasive grits in grinding is negative, which makes the process more efficient and results in higher thermal loads compared to milling.

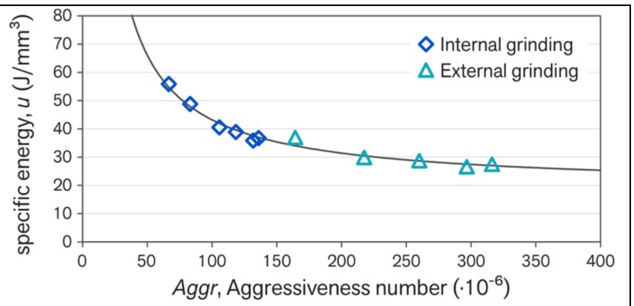
~~a.~~ d. The specific energy required to remove a unit volume of material in grinding is higher than in milling, leading to increased thermal loads.

18. What are the three mechanisms of grinding-wheel wear? *[3p]*



19. Define specific grinding energy and elaborate on its implications. What is size effect? *[5p] – ADVICE: include an illustration of a typical specific energy curve with the units.*

- A fundamental parameter derived from the tangential force (or power) and grinding conditions is the specific grinding energy, which is defined as the energy per unit volume of material removal.
- The particular significance of the specific energy is that provides insight into material-removal mechanisms (e.g., rubbing, plowing, cutting).
- The size effect is a characteristic feature of a grinding process, characterized by a large increase in specific energy with decreasing aggressiveness.



$$u = \frac{F_t \cdot v_s}{v_w \cdot a \cdot b} = \frac{P}{Q_w}$$

(Abrasive fine-finishing processes) *[6p]*

20. Which of the following statement(s) about finishing technology is/are true? *[2p]*

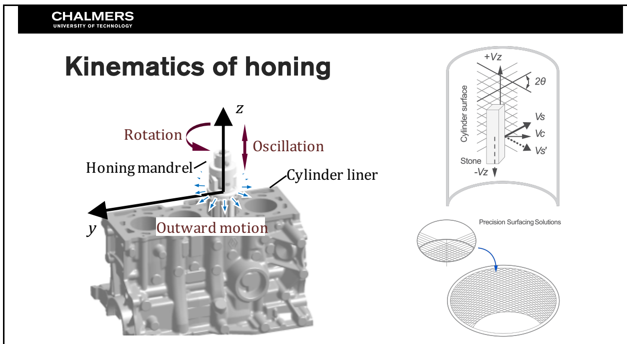
a. Finishing operations, such as grinding, hard turning, and abrasive fine finishing, are crucial for achieving the highest quality in form, accuracy, and surface integrity at the end of the manufacturing process chain.

b. Finishing technology is the intermediate step in the manufacturing value chain, setting the foundation for subsequent material-conversion processes such as forging.

c. Finishing technology is used primarily for controlling geometrical tolerances and surface finish ensuring that the component meets the specifications of precision components.

d. Abrasive fine finishing is mainly used at the beginning of the manufacturing process to prepare the material for subsequent machining and thermal treatment.

21. Describe and illustrate a honing operation along with the process kinematics. What are the main process parameters? *[4p]*



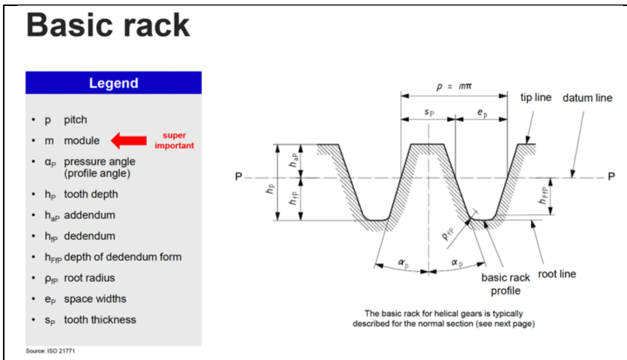
Honing is an abrasive process used in finishing the bores (inside diameter) of internal combustion engines and gears. The process uses fixed abrasive tools – abrasive stones (sticks) – as the cutting medium

The main process parameters are:

- Rotation (of the mandrel)
- Oscillation (of the mandrel)
- Outward pressure (of the stones)

(Processes for manufacturing of gears) *[6p]*

22. What pre-conditions must be given, that a tool can be used for different gear geometries (e.g. different number of teeth)? *[3p]*



The basic pre-condition for using a cutting tool such as a hob to machine different gear geometries with different numbers of teeth is that the module (of the basic rack) is the same for both the tool and the gears.

The basic rack is an imaginary profile that serves as a reference for both tool and the gear being machined.

23. Noise of gears is one of the key requirements. What type of gear finishing do you recommend and why? *[3p]*

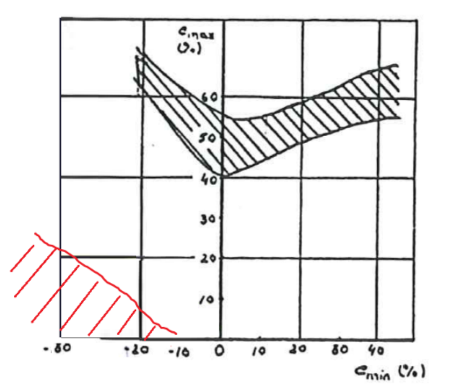
This question addresses the motivation for the additional finishing operation of gears, typically after heat treatment. To minimize gear noise, gear honing is recommended as a finishing process because it improves surface smoothness, corrects minor tooth profile errors (waviness), resulting in quieter operation due to improved meshing accuracy. Similar functional performance of the gear can be achieved by “superfinishing / gear polishing”.

(Metal forming processes) *[13p]*

24. Explain how lubrication could affect formability in general (answer for deep drawing)? *[5p]*

Can be described for deep-drawing and limiting drawing ratio as a measure of formability: In deep-drawing you need blank-holder force to prevent wrinkling. With lower friction: At the blank-holder force needed, you can use a larger blank (larger sheet diameter) – and the material can still move inwards => thus deeper parts are possible. And thus maximum (or limiting) drawing ratio will be larger. (It could be discussed more generally that the material properties doesn't change, but the possibility to form more increases as friction creates forces that will lead to fracture).

25. Explain *where (approximately)* in a Forming Limit Diagram one would find indication of wrinkling. (Draw an FLD) [4p]



In the lower left corner, and to the left, see fig. When e_{min} (very) negative = there is a lot of compression - then the risk of wrinkles is the highest. Especially if e_{max} is small there is a drive towards wall thickening which can lead to wrinkles. (Can be avoided by control of blank-holder forces, as long as the area to "hold" on isn't too large).

26. Which of the following statement(s) about hydroforming is/are true? *[2p]*

a. Wrinkling is typically associated with a too low axial force.

b. Fracturing is associated with too high pressure (of the fluid).

c. Wall thickness after hydroforming is less uniform than after deep drawing since it is difficult to keep process parameters constant.

d. Bending of tubes is a common process prior to the hydroforming step.

27. Which of the following statement(s) about press hardening (hot stamping) is/are true? *[2p]*

a. Parts are first heated, secondly formed while in the hot state and then rapidly cooled (quenched), still in the dies.

b. The parts made with press-hardening will have a low strength, but the ductility of the part will be higher after the process than before.

c. The steels used are often called Boron-steels as they contain Boron which increases hardenability.

d. The hardening is made by pressing the sheet metal, thus causing a strain-hardening - which gives the steel its strength.

(Joining processes) *[6p]*

28. Describe how two pieces of material are joined by soldering or brazing. That is - what keeps the parts together? Also, shortly in very general terms describe the procedure for soldering/brazing.

The solder has another composition and lower melting temperature than the workpieces. During soldering an alloy is formed in the zone in between the solder and the workpiece material through diffusion. The zone is thin and called diffusion zone. For instance, with Sn-based solder on Cu is formed Sn-Cu in the diffusion-zone. So, it is a solid bonding (not as adhesives or such), but the workpiece has not melted (as in welding). The procedure: 1) Heat workpieces; 2) Fluxing (remove oxides & promote wetting); 3) Solder application => solder melts => wetting + diffusion, then solder solidifies; 4) Cleaning

(Data-driven manufacturing processes) *[6p]*

29. Describe the levels in the ISA-95 Pyramid and why it is important to use it in developing Industry 4.0 solutions. *[4p]*

Levels in the ISA-95 Pyramid: • Level 0: Process - The physical layer containing sensors and actuators that interact directly with the manufacturing process. • Level 1: Control - Real-time process control managed by Programmable Logic Controllers (PLCs). • Level 2: Supervisory Control - Monitoring and supervision using Human-Machine Interfaces (HMI) and Supervisory Control and Data Acquisition (SCADA) systems. • Level 3: Operations Management - Management of operations like inventory and quality through, e.g. Manufacturing Execution Systems (MES). • Level 4: Business Planning and Logistics - Enterprise-level operations handled by ERP systems.	The ISA-95 pyramid is important in the development of Industry 4.0 solutions because it provides a standardized framework for integrating enterprise and manufacturing systems. By defining different levels of operation, it ensures a smooth flow of data from the shop floor to the higher hierarchies, enabling real-time, data-driven decision making. This structure facilitates the seamless integration of information technology (IT) and operational technology (OT) systems, promoting effective communication between management and production processes. In addition, ISA-95's layered approach helps create robust security strategies by isolating critical systems from potential threats.

30. Which of the following statement(s) about the role of data in data-driven manufacturing processes is/are true? *[2p]*

a. Data engineers focus on building infrastructure for collecting, storingand processing data.

b. Data management ensures data's reliability, consistency, and security.

c. Data scientists are responsible for ETL (Extract, Transform, Load) processes and database design for manufacturing operations.

d. Data management tasks include data modeling, machine learning, and visualization.

(Bonus questions – "Technological Shifts in Surface Metrology") *[10p]*

31. Briefly explain one major technological shift in surface metrology and describe how it improves on traditional methods like stylus instruments. *[3p]*

A major technological shift in surface metrology has been the adoption of optical methods such as confocal microscopy and interferometry. Unlike stylus instruments, optical methods are non-contact, preventing surface damage. In addition, optical methods provide higher resolution and can measure surfaces in three dimensions (areal measurements), allowing faster data collection over larger areas.

32. Which of the following statement(s) about surface classifications in modern metrology is/are true? *[2p]*:
    a. Structured surfaces have a deterministic pattern designed to meet specific functional requirements, such as reducing friction or improving hydrodynamics.
    b. Stochastic surfaces contain randomly organized surface features often seen in processes like superfinishing, where textures can increase load-bearing capacity.
    c. Deterministic patterns are used only for decorative purposes and do not affect the function of a surface.
    d. Stochastic surfaces have predictable, repeating patterns designed specifically for the surfaces to look good.

33. How do surface measurement techniques help establish a functional correlation between surface texture and performance? Provide an example. *[3p]*

Advanced surface metrology techniques, such as confocal microscopy, help optimize manufacturing performance by providing detailed three-dimensional information about surface texture. For example, in tribological systems, confocal microscopy can measure surface roughness and waviness with high precision, allowing manufacturers to reduce friction. These precise measurements help ensure that surfaces meet the functional requirements of the product, optimizing its performance in real-world applications. NOTE: there are many possible answers to this question

34. Which of the following statement(s) about recent technological shifts in surface metrology is/are true? *[2p]*:
    a. Technological advancements in surface metrology have been driven by the need to accurately characterize complex surface features for precision engineering.
    b. Miniaturization in manufacturing has increased the importance of texture and feature positioning in surface characterization.
    c. Traditional surface metrology is fully capable of meeting the precision and complexity requirements of manufacturing processes without any modifications.
    d. Size is now considered the only critical attribute for surface functionality in all advanced manufacturing processes so the characterization of surfaces is rubbish.