CHALMERS
UNIVERSITY OF TECHNOLOGY

EXAM

COURSE	**Manufacturing processes**
COURSE CODE	**MPR034**
STUDY YEAR/PERIOD	**2025/2026 Study Period 1**
EXAMINER	**Peter Krajnik**
DATE OF THE EXAM	**2025-10-28**
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 28 exam questions (100 points)** • **Extra 4 bonus questions (max. 10 points)**

SPECIFIC INFORMATION

This exam combines:

- **True or false / multi-choice questions (22 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 (78 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*	*a., c.*
11	*2*	*b., c.*
12	*2*	*a., c.*
13	*2*	*c., d.*
14	*2*	*c., d.*
20	*2*	*b., d.*
23	*2*	*a., b.*
24	*2*	*b., d.*
25	*2*	*a., c.*
27	*2*	*b., c.*
28	*2*	*c., d.*
TOTAL	*22*	

Bonus questions	*Points*	*Letter/s indicating true answers*
30	*2*	*b., d.*
32	*2*	*a., c.*

(Manufactured surfaces) *[5p]*

1. Which of the following statement(s) about the contact measurements of machined surfaces is/are true? *[2p]*
    a. The measurement direction should be orthogonal to the lay direction.
    b. The measurement direction should be parallel to the lay direction.
    c. The measurement direction should be across the dominant texture.
    d. The measurement direction should be in random directions.

2. What is the difference between negative profile skewness parameter R_{sk} and a positive one? (describe also a functional surface requirement associated with R_{sk}) *[3p]*

The profile skewness parameter (Rsk) describes the asymmetry of a surface roughness profile relative to its mean line.

- A negative Rsk: indicates that the surface has more dales than peaks. Such surfaces are desirable for bearing and sliding applications because they provide better oil retention, lower friction, and improved wear resistance.

- Positive Rsk: The surface has more sharp peaks than dales, i.e., the texture is dominated by peaks. These surfaces tend to cause higher friction and wear.

(Non-conventional processes) *[16p]*

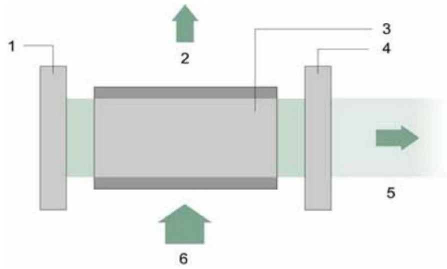
3. Define and explain at least three macro-geometrical defects one might find on an abrasive waterjet cut part. For two of the defects, you should also explain the cause. (Explanation of type of defects in question: form errors or geometrical errors which are NOT part of the surface topography). *[7p]*

Tapering is an angle due to difference in width between the top and bottom of the cut, resulting in a wider top and narrower bottom. This occurs because the jet loses energy as it penetrates deeper into the material, reducing its cutting effectiveness at the bottom.

Lag-induced corner-defects happens when the jet lags behind the intended cutting path, especially at direction changes. This causes the bottom of the cut to deviate from the top, leading to inaccuracies in the final geometry. The primary cause is having a (too) constant cutting speed even when the tool path changes direction. Reducing speed in corners can help.

Edge rounding is another defect where the edges of the cut are not sharp but slightly rounded. This can be due to the nature of the jet's impact and the erosion mechanism at the material's surface. (Here thus explaining all three – only 2 necessary for full p).

4. Describe a laser source (make a sketch). Describe the different functions (parts) of the system and their respective purpose. *[5p]*



See fig: 3: active medium, which can be a gas (like CO_2), a solid (like Nd:YAG), or a doped fiber.
The medium is excited using pumping energy (6), typically from electrical discharges or flash lamps. The fully reflecting mirror (1) and the semi-reflecting mirror (4) contain the medium and 4 allows the beam (5) to exit/be created. Further a cooling system (2) to manage heat.

5. Shortly describe the function of the EDM process – what happens and how is material being removed. What basic machine components are there to make the EDM function? *[4p]*

EDM removes material using electrical discharges (sparks) between an electrode and a conductive workpiece, both in a dielectric fluid. When the voltage is high enough, a plasma channel forms, melting and vaporizing small amounts of material, which are then flushed away by the expanding gas bubble. The basic machine components include (3 should be mentioned):

- Pulse generator/power supply to generate the discharges (could also say an RC-circuit)
- Electrode (tool),
- Dielectric fluid system (for insulation, cooling, and debris removal),
- and a servo system to maintain the correct gap between electrode and workpiece.

(Metal-cutting and metal-forming machines) *[8p]*

6. Spindle design must meet requirements from three perspectives: the machining process, the bearing system, and the motor/drive unit. Briefly explain at least two key requirements from each of these three perspectives. Clarify how these requirements influence the overall spindle design. *[4p]*

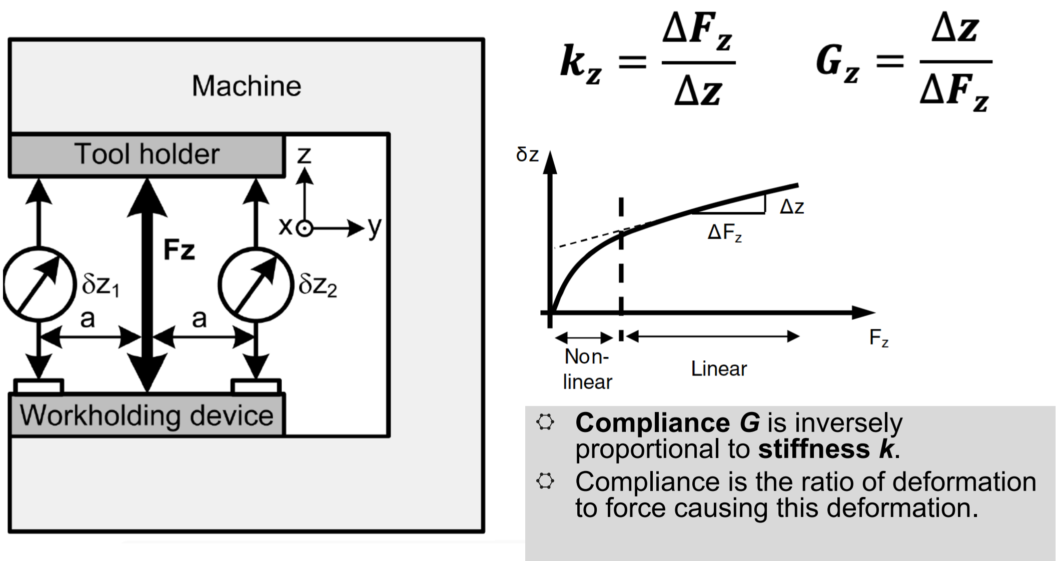
- Machining process requirements:
  - Power & torque delivery: The spindle must deliver sufficient torque and power at required cutting speeds to match the material removal demands → This influences motor sizing and cooling requirements.
  - Speed capability: The spindle must support high rotational speeds required for high-speed milling (especially in aerospace) → Drives the selection of high-speed (hybrid) bearings.

- Bearing system requirements:
  - Radial & axial load support: Bearings must withstand cutting forces in both directions while minimizing deflection → Affects bearing type, number, and preload strategy.

- Thermal stability: Bearings must maintain stiffness despite thermal expansion due to speed and load → Requires proper preload management and thermal compensation (e.g. O-arrangement, spring preload).

- <u>Motor/Drive system requirements</u>
    - Torque–speed curve: The spindle's torque must remain sufficient across the full speed range → Determines choice between asynchronous or synchronous motors.
    - Drive control precision: The drive must accurately control spindle acceleration, deceleration, and positioning → Impacts the feedback system, cooling, and inverter design.

7. Define the term 'static stiffness' as it pertains to a press. Discuss the methodologies used for its experimental determination via measurements. How does static stiffness correlate with static compliance? *[4p]*



The static stiffness of a press (or any structure) is defined as its ability to resist (elastic) deformation/displacement when loads are applied. High stiffness means that more force can be applied with minimal displacement.

For an elastic body with a single degree of freedom (DOF), the stiffness is defined as:

$k_z = \frac{\Delta F_z}{\Delta z} \left[\frac{N}{\mu m}\right]$ (Stiffness is typically measured in Newtons per micrometer)

where:

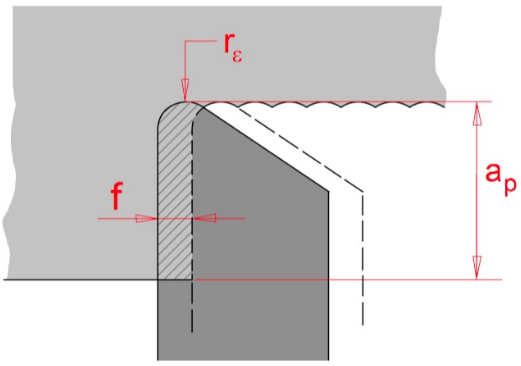
- ΔF_z is the force on the body/press
- Δz is the displacement produced by the force along the same degree of freedom (in the z direction in the illustrated case).

Experimental determination of static stiffness can be done most easily using the force-displacement method (illustrated in the figure above – left), where the structure is loaded with a known/controlled static force ΔF_z and its displacement/elastic deformation Δz is measured (e.g., using micrometer dial indicators). The applied load can then be divided by the measured displacement to obtain static stiffness.

Static compliance is the inverse of stiffness, i.e., $G_z = \frac{\Delta z}{\Delta F_z} \left[\frac{\mu m}{N}\right]$. A structure that is highly compliant displaces significantly when a load is applied. Therefore, a structure with high static stiffness will have low static compliance and vice versa.

(Machining processes and machinability) *[18p]*

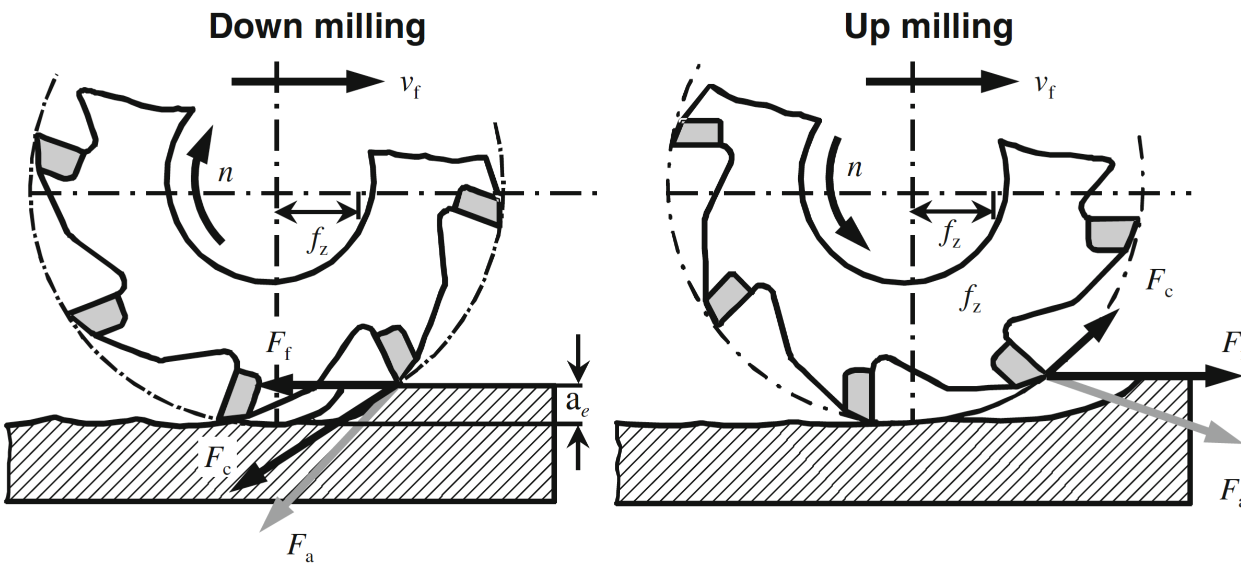
8. Discuss how the theoretical surface roughness R_{th} changes with the feed and the nose radius. What would you do to reduce R_{th} in turning? Are there any negative aspects with respect to using a smaller nose radius? *[3p]*



$$R_{th} = \frac{f}{8 \cdot r_\varepsilon}$$

- In an ideal case the theoretical surface roughness R_{th} increases with a feed f and decreases with a nose radius r_ε.
- To reduce R_{th}: use a smaller feed rate and/or a larger nose radius.
- The negative aspects of using a smaller nose radius: worse R_{th}, weaker edge, and reduced ability to carry load. It's chosen for lowering forces, not for the surface finish.

9. Schematically illustrate (peripheral) milling process and explain the difference between down- and up-milling operation. *[4p]*



- In **down milling**, the cutting tool is fed with the direction of rotation. In down milling, the insert starts its cut with a large chip thickness. This prevents the edge from rubbing against the surface before engaging in the cut.
- In **up milling**, the feed direction of the cutting tool is opposite to its rotation. The chip thickness starts at zero and increases toward the end of the cut. The cutting edge is forced into the cut, generating rubbing.

10. Explain how each of the following tool geometrical parameters affects the turning process: (i) Entering angle κ_r; (ii) Rake angle γ_0; (iii) Inclination angle λ_s; (iv) Nose radius / minor-edge geometry. For each parameter, state what it influences and give one practical consequence of increasing it. *Keep your answers concise – one to two sentences per item. [5p]*

- Entering angle: It governs how the chip forms and flows along the edge and steers the force direction.
- Rake angle: More positive rake lowers cutting forces and cutting temperature; more negative rake strengthens the edge and often improves chip breaking.
- Inclination angle: a negative inclination increases effective wedge angle → stronger edge OR positive inclination increases effective rake (easier cutting) but reduces edge strength.
- Nose radius & minor edge geometry: these set the surface finish. A larger nose or a wiper minor edge flattens the feed marks.

11. Which of the following statements about indexable drills is/are true? *[2p]*

a. The cutting speed in drilling is uniform across the tool radius.
b. The central insert in an indexable drill works from 0 up to ~50% of the maximum cutting speed.
c. The peripheral insert operates from 50% up to 100% of the maximum cutting speed.
d. The central insert generally sees the easiest cutting conditions because the forces are lower at small radii.

12. Which of the following statements about tool wear mechanisms in machining is/are true? *[2p]*

a. Abrasive wear occurs when hard particles or hard phases in the workpiece scratch the tool surface, typically under high stress.
b. Diffusion wear is most severe at low cutting temperatures and low strain rates.
c. Adhesive wear results from localized welding between tool and workpiece materials under high pressure and moderate temperature.
d. Oxidation wear dominates mainly at very low temperatures and high humidity.

13. Which of the following statements about difficult-to-machine materials is/are true? *[2p]*

a. Titanium alloys are easy to machine because they conduct heat away efficiently.
b. Work hardening reduces cutting forces and prolongs tool life in superalloys.
c. Titanium and nickel-based alloys maintain high strength at elevated temperatures, which accelerates tool wear.
d. Nickel-based alloys often have poor thermal diffusivity, leading to very high temperatures of the cutting tool.

(Metalworking fluids) *[5p]*

14. Which of the following statement(s) about water-miscible fluids is/are true? *[2p]*

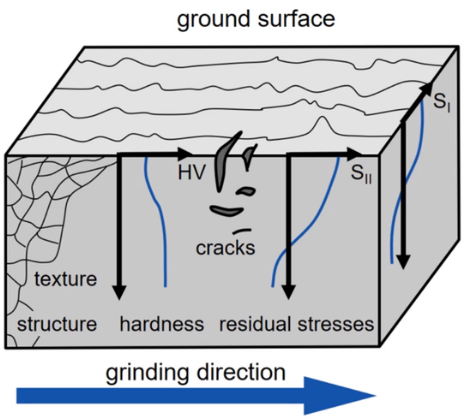
a. Straight oil is usually mixed with water, either as an emulsion or as a solution.
b. Emulsion is a solution of oil in water. The result is a single-phase liquid.
c. Water-miscible fluids are considered more sustainable compared to straight oils as they mainly contain water.
d. Emulsion is a compound of two liquids that don't fully mix. Their suspension needs to be stable.

15. What is MQL? Briefly explain the technology, its main benefits and successful applications in the industry. *[3p]*

MQL (minimum quantity lubrication) is a near-dry machining method that uses a very small amount of straight oil lubricant delivered to the cutting zone. This technology mixes compressed air with finely “atomized” oil (oil droplets), which is then fed through external nozzles or internal tool channel (single) to reach the tool–chip interface. The main benefits of MQL are reduced coolant consumption and costs, cleaner process, better lubrication at the contact zone, and improved sustainability. MQL has been successfully applied to the machining of aluminum and cast-iron components, particularly for drilling and milling in automotive production lines.

(Grinding processes) *[8p]*

16. Grinding creates high temperatures. How are elevated temperatures affecting surface integrity? *[3p] – ADVICE: describe different types of thermal damage and how these affect surface integrity*

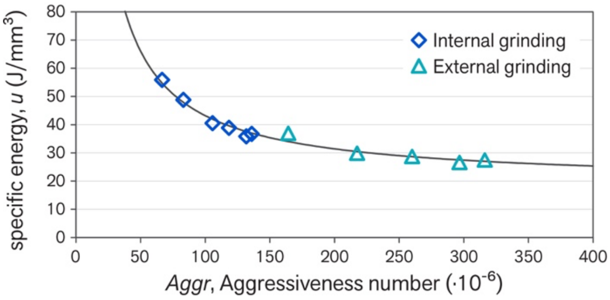


The high temperatures produced can cause various types of thermal damage to the workpiece, such as burning, phase transformations, softening (tempering) of the surface layer with possible rehardening, residual tensile stresses, and cracks.

- Grinding burn: Local overheating causes visible discoloration.
- Softening (tempering): Surface is heated above its original tempering temperature, leading to a softened layer with reduced hardness.
- Rehardening burn / phase transformation: Surface is austenitized and rapidly quenched, forming hard but brittle layer over a softened subsurface, which promotes cracks.
- Unfavorable residual tensile stresses: Rapid heating and cooling produce tensile stresses in the surface, lowering fatigue resistance.
- Cracks: Repeated thermal cycles create surface or transverse cracks that act as immediate failure initiators.

17. 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 power (or tangential force) and grinding conditions is the specific grinding energy, which is defined as the energy per unit volume of material removal.
- From a fundamental perspective, the particular significance of the specific energy is that any mechanism of abrasive-metal interaction (e.g., rubbing, plowing,



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

cutting) must be able to account for its magnitude and its dependence on the process parameters.

- A distinctive characteristic of a grinding process is a large increase in specific energy with decrease in aggressiveness. This phenomenon is known as size effect.

(Abrasive fine-finishing processes) *[5p]*

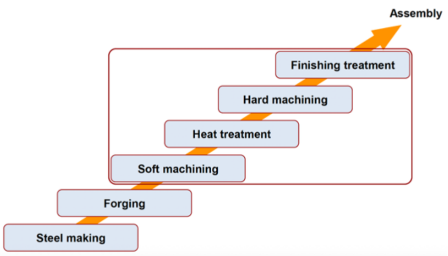
18. Plateau-honed cylinder liners are typically characterized using different surface texture parameters. Explain the functional meaning of the following parameters: Rpk, Rk, and Rvk. How do these parameters relate to the tribological performance of the liner? *[5p]*

- Rpk (Reduced Peak Height): Represents the height of the peaks above the core. Peaks wear away quickly during the running-in process. Its function is to minimize initial friction and wear.
- Rk (Core Height): The depth of the central load-bearing zone. Its function is to provide stable support for piston ring load and ensure durability.
- Rvk (Reduced Pit Depth): The depth of the valleys below the core. Function: Retains lubricant and maintains lubrication film.

These parameters describe how a plateau-honed surface balances running-in wear (Rpk), load support (Rk), and lubrication capacity (Rvk), which are all crucial for the tribological performance of engine liners.

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

19. Describe a typical process chain for a gear in an automotive transmission, starting from steel making and ending at assembly. Highlight the role of each major stage. *[4p]*



- Steel making: Produce specified steels with controlled chemistry and cleanliness to ensure durability.
- Forging: Shape the gear blank and refine the grain flow to improve strength.
- Soft machining: Turn, bore, drill, and rough-cut gear features into a near-net shape.
- Heat treatment: To achieve the required surface hardness and core toughness.
- Hard machining: Often grinding to obtain the accuracy (geometry) of the gear flanks.
- Finishing treatment: Honing or polishing to reach the surface quality.

20. Which of the following statements about gear broaching is/are true? *[2p]*

a. The depth of cut can be adjusted during machining to accommodate different gear designs.
b. Each broach is designed for one specific gear geometry, which limits flexibility.
c. The process is mainly used for producing external gears with complex contours.
d. The complete gear profile is machined in one pass using a tool shaped as the negative of the gear.

(Metal forming processes) *[17p]*

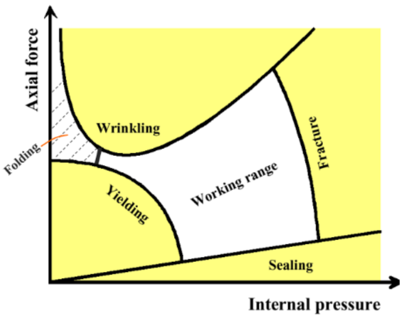
21. Sheet-metal forming: How can the material's strain hardening (or deformation hardening) have an effect on the formability? Discuss (shortly) especially how more deformation can be possible given certain strain hardening. *[6p]*

Strain hardening improves formability in sheet-metal forming by increasing the material's strength as it deforms. As the material is stretched, it becomes stronger and more resistant to further deformation in localized areas. As a result, strain is more evenly distributed across the sheet, especially reducing the risk of necking or early failure. That is – the neck last longer – it will be wider – but not resulting in a fracture directly. This allows for greater overall deformation before fracture, enabling more complex shapes to be formed.

22. For hydroforming (with a tubular starting object) describe:
- Why and how wrinkling occurs
- Why and how fracture (cracks) occurs.

(Preferably use some figure/graph to explain your answer). *[5p]*

See figure:
Wrinkling occurs at excessive axial force, especially if internal pressure is also low.
Fractures on the other hand occurs at high pressure levels – where you try to "inflate" the tube too much, especially in the end of the cycle where fine radii are to be created.



23. Which of the following statement(s) about forming-limit diagrams (FLD) is/are true? *[2p]*
a. In an FLD there is a limit line – over which you get a fracture. And under the limit line you are in the safe-zone.
b. When using an FLD you calculate *e-max* and *e-min,* which are strains calculated from how a circle on the sheet has been deformed in the plane, e-max being the largest deformation of the circle.

c. In an FLD you always have at least 5 different limits (lines) which have been made at different speeds of forming.
d. FLDs are only useful for deep-drawing.

24. Which of the following statement(s) about sheet-metal formability is/are true? *[2p]*
a. Good formability is defined as having a low force for the forming.
b. A more high-strength steel typically has worse formability than an ordinary “lower-strength” steel.
c. In deep-drawing the limiting drawing ratio (LDR) is not a good way to quantify formability and its mathematical definition, LDR=ln(D/R) where D is the blank diameter and R the blank radius, tends to give varying results.
d. Higher normal anisotropy ($r > 1$) means better formability since the strain in the thickness direction will be smaller than in the plane (less thinning and less risk of fracture).

25. Which of the following statement(s) about press hardening (hot stamping) is/are true? *[2p]*
a. With press hardening you can make more complex shapes than with cold forming high-strength steels.
b. Welding of press-hardened parts is much easier than welding of cold-formed parts.
c. Tooling cost for press hardening is higher (than for cold-forming) since the dies have cooling channels.
d. The sheet material used in press-forming has quite high content of Bismuth, to improve hardenability, and the steels are called Bismuth-steels for that reason.

(Joining processes) *[8p]*

26. Resistance spot welding (RSW):
- Describe how RSW works! Include at least two process parameters in your answer.
- Compare laser-welding with RSW. Shortly explain the pros- and cons based on the functions or principles of each process.

RSW works by clamping two or more metal sheets between cooled copper electrodes (in a welding “gun”) and passing a high electric current. The resistance in between the contact surfaces generates heat, melts the material locally, forming a weld "nugget" when solidified. Two important process parameters are weld current and weld time (too much of either can cause excessive heat and defects, while too little may result in weak joints). Electrode force can also be mentioned.
Laser welding uses a focused laser beam to melt the material typically along a seam. It allows single-sided access, giving new design possibilities. Compared to RSW, laser welding offers higher speed, narrower welds and a sealed seam. However, it requires higher investment, precise part positioning (no clamping by a gun like in RSW), it can also be mentioned that it has greater sensitivity to corrosion, or that repair work is less straight-forward.

(Data-driven manufacturing processes) *[4p]*

27. Which of the following statements about the ISA-95 Pyramid is/are true? *[2p]*
    a. Level 3 of the ISA-95 Pyramid focuses on real-time process control using PLCs.
    b. ISA-95 provides a standardized approach for integrating enterprise and manufacturing systems.
    c. The ISA-95 Pyramid ensures smooth data flow from the shop floor to the high-level (management) floor, enabling real-time decision-making.
    d. Level 4 of the ISA-95 Pyramid is responsible for monitoring and supervisory control using SCADA systems.

28. Which of the following statements about technology perspectives in a connectivity solution are true? *[2p]*
    a. Connectivity solutions must use only one communication protocol at a time to ensure data consistency.
    b. The main role of a connectivity solution is to store data permanently for historical analysis.
    c. An event-driven architecture helps manage large volumes of data by reacting to events instead of using constant polling.
    d. High data telemetry throughput (e.g. machine-tool sensors) means the system can process and send many data messages per second.

(Bonus questions: Sustainable machining) *[10p]*

29. Cutting tool materials contain raw materials that are not abundant and raise concerns. Their elimination/replacement seem not feasible. How can tool manufactures improve their sustainability? *[3p]*

There are many ways of doing this. Here are some promising approaches:

- Close the loop by raising carbide tool take-back and high-yield recycling. Prioritize direct methods (zinc/crushing). Develop logistics and customer programs to prevent losses at the end of the product's useful life.
- Adopt exchangeable inserts with more edges, smaller inserts where the depth of the cut allows, and combination tools so that only the cutting tip contains WC–Co while the bodies are reused. This reduces demand for critical raw materials.
- Extend the life of tools and keep them in circulation by regrinding and recoating.

30. Which of the following statement(s) about sustainable machining is/are true? *[2p]*
    a. Most machining greenhouse gas emissions are Scope 1
    b. Exposure to metalworking fluids is a recognized health risk
    c. Planetary boundaries can be directly allocated to a single machine
    d. Traceability tools can support social responsibility in supply chains

31. Compared to metal forming, metal cutting generates a significantly higher proportion of waste. How can the associated impacts be minimized? *[3p]*

There are many options. Here are some approaches:

- Go near-net, then finish machine: Shift roughing to near-net routes (casting).
- Upgrade chip circularity (quality and route). Keep the chips clean and segregated to prevent alloy mixing and coolant contamination.
- Use machining strategies and parameters that improve surface integrity (e.g. favorable residual stresses) to extend fatigue life, thereby reducing replacement rates and the downstream material and energy burden.

32. Which of the following statement(s) about improving energy consumption in machining is/are true? *[2p]*:
    a. Increasing the material-removal rate (within quality limits) generally lowers specific energy and shortens process time.
    b. High-pressure coolant always reduces total energy because pump power is negligible compared to the cutting power.
    c. Measures to minimize idle time and "air-cutting"/rapid traverses reduces energy consumption.
    d. Auxiliary systems represent a minor (<10%) share of energy consumption, so optimizing them yields little benefit.