Technical Requirements
1. Welding System:
- Type: Laser welding or arc welding.
- Power: 1-5 kW.
- Wavelength: 1064 nm (laser) or 400-700 nm (arc).
2. Handling System:
- Type: Robotic arm or cable-based manipulation system.
- Range: 1-5 meters.
- Accuracy: ±0.1 mm.
3. Propulsion System:
- Type: Ion engine or nuclear propulsion system.
- Thrust: 1-100 N.
- Efficiency: 30-50%.
4. Control and Communication System:
- Type: Computer-based control system or radio communication system.
- Data rate: 1-100 Mbps.
- Range: 1-100 km.

Materials and Components
1. Robot Structure:
- Material: Aluminum or titanium.
- Weight: 100-500 kg.
2. Welding System:
- Laser: Diode or Nd:YAG.
- Arc: Tungsten or copper electrode.
3. Handling System:
- Robotic Arm: Electric or hydraulic motors.
- Cable-based Handling System: Electric or pneumatic motors.
4. Propulsion System:
- Ion Engine: Xenon or argon.
- Nuclear Propulsion System: Nuclear reactor or radioisotope generator.

Steps to Build the Robot
1. Design and Simulation:
- Use computer-aided design (CAD) and simulation software.
- Perform stress and vibration analysis.
2. Selection of Materials and Components:
- Select appropriate materials and components for the robot.
- Consider factors such as weight, strength, and efficiency.
3. Construction and Assembly:
- Build and assemble the robot.
- Perform testing and make necessary adjustments.
4. Testing and Validation:
- Perform testing under laboratory conditions and in space.
- Validate robot operation and make necessary adjustments.

Costs and Timescales
1. Costs:
- Estimated: $10 million - $50 million.
- Depending on the size and complexity of the robot.
2. Timescales:

- Development: 2-5 years.
- Construction and assembly: 1-3 years.
- Testing and validation: 1-2 years.

REALISTIC SPACECRAFT DESIGN FOR OPERATION NEAR A "DARK WHITE STAR" (THEORETICAL HYBRID STAR)

This as a theoretical spraceraft concept inspired by current reat vold technologlach, such as Merlln engines of Falcen 2, Parker Salare Prode. and deep space autonomous operations. it s desined 10 reprate in ereaed thmolenal iromrdls

ROBOTIC AND MINING SYSTEMS

The spacecraft includes Autonomuna. repotic arms, nspned by Canadurm and Perseverancs, Mars Rover Syots. These arms, are covered with high-resistence ceramic and carpon-riber insulation albving comact with plasnna jots enercers matter around the star tactn rerote tyd system can deplts setentic instruments in mamplaiisters or presire ehcemanicals,

SENSOR AND COMMUNICATION SYSTEMS

Advanced LIDAR arrays. based faser interferometry and alomic clock . syhchnonicration are used to naap grovitational probients and safe-nearing equilibAum zanes. These arrays generate reauat-time models of the warpesl stemes goormatry fireo the Dark White Star A nudelur-far traisla.

PROPUISION ENE EGY SYSTEMS

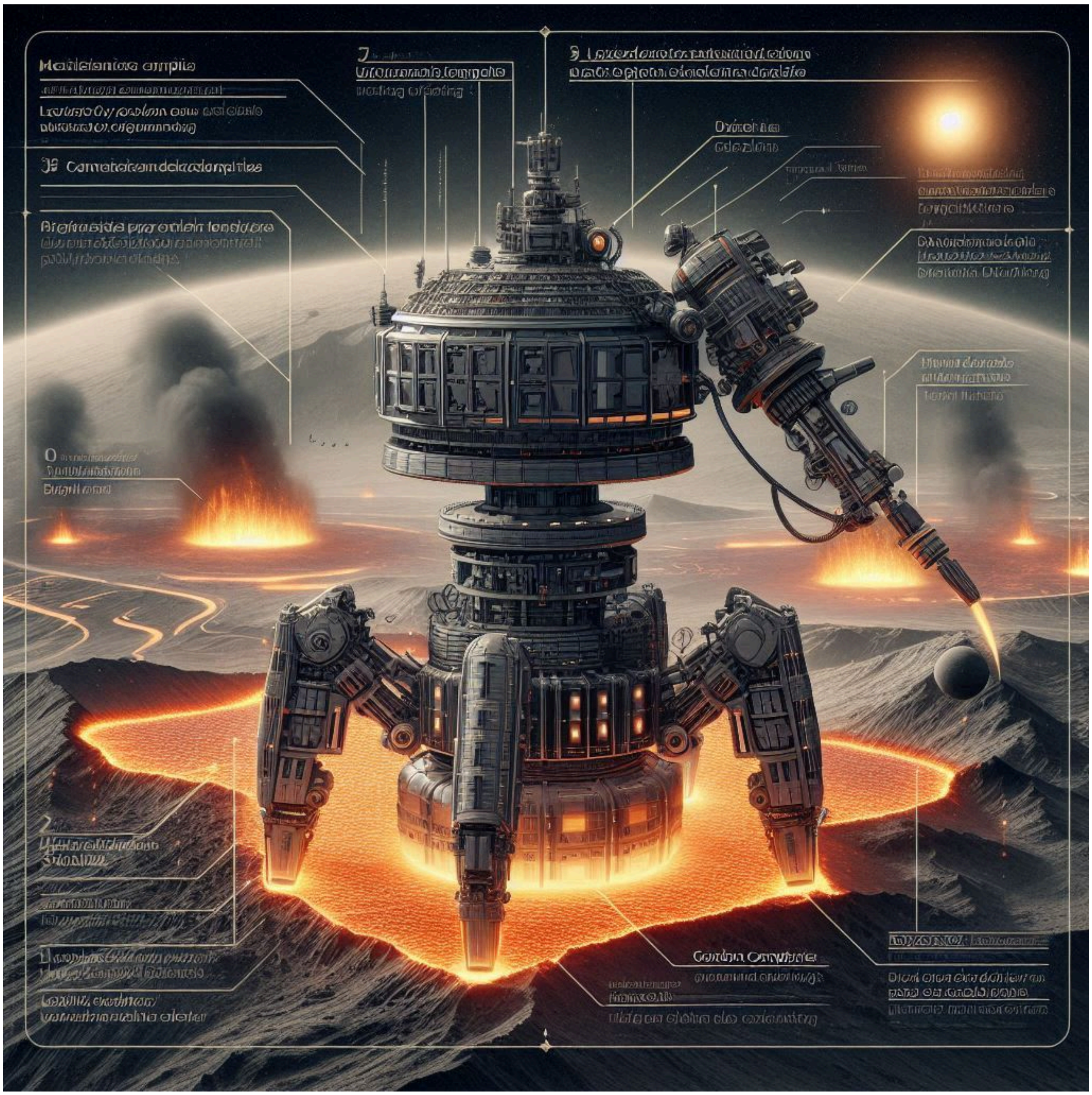
Advanced LIDAR arrays based on laser inteifferometry and atonre clock synchronization are used to map ora vitational predients and safe.flioning eu aiibiium zones. These arrays generate rea-time niedies of themoraed descetieg apomer nesy.the Dane White Stiar bly souik Ralitel jpoh thrusters vunition aisting blasmad-indures Chandles, and Bergiium godlam-nifnrors for roTransmission,

MATERIALS & STRUCTURAL COMPONErs include Graphene mutilavered coatings for conductive shiekiing and thermal dimsitution-are uned to. maiz gravitational gradients, and safe-duating rer auinimum povec. , onllowing coidicugus maChanization-comportents (lor oncludkin starch afer Introrturine patro the spaceorch includes duamum communication linke of conductive shididing and eatraction fyswes, and allows the compurrit-regengtation of tools, huit parches, and structarral extensions, rib This ship canitemain indefiintelyiin crbii, proviced that dravlutitni ialsfureuina provieto) Thought urneasivaks, these may include telecommunizations hubs resource exiractors, of data relays inside sterill noomcn atellar pnenomend presson unfeacuis

```
| AUTONOMOUS SPACE WELDING AND MOLDING ROBOT |

| +-----------------+ +-------------------+ +-------------------+ |
| | LIDAR SENSORS | | OPTICAL CAMERAS | | THERMAL SCANNER | |
| +--------+--------+ +---------+---------+ +---------+---------+ |

| +------------v------------+ |
| | VISION SYSTEM | |
| | + DIAGNOSTIC AI | |
| +------------+------------+ |

| +-----------------------v-----------------------------+ |
| | CENTRAL CONTROL MODULE (RTOS + ADVANCED AI) | |
| +---------------------------+---------------------------+ |
| | |
| +---------------------------v---------------------------+ |
| | SPACE NAVIGATION AND PROPULSION SYSTEM | |
| | - Ion Engines (Xenon/Argon) | |
| | - Attitude Correction and Stabilization | |
| +---------------------------+---------------------------+ |

| +---------------------------v---------------------------+ |
| | MULTIFUNCTIONAL WELDING AND MOLDING MODULE | |
| | - ND:YAG Laser Welding (1–5 kW) | |
| | - Carbon-Carbon Melting | |
| | - Ceramic Induction Furnaces | |
| +---------------------------+---------------------------+ |

| +---------------------------v---------------------------+ |
| | ROBOTIC ARMS (1–5 m / ±0.1 mm) | |
| | - Thermal Tweezers | |
| | - Cutting, Polishing, and Scanning Module | |
| +---------------------------+---------------------------+ |

| +---------------------------v---------------------------+ |
| | RAW MATERIAL AND ADDITIVE MANUFACTURING SYSTEM | |
| | - Metal Powder Capsules | |
| | - Selective Laser Melting | |
| +---------------------------+---------------------------+ |

| +---------------------------v---------------------------+ |
| | COMMUNICATION AND SPACE TELEMETRY MODULE | |
| | - Data Laser (1–100 Mbps) | |
| | - Redundant Quantum Link | |
| +---------------------------------------------------------------+ |
```

| Quantum Antennas and Modules | Graphene + Evaporated Gold Structure | High Speed and Optical Efficiency || EMI Protection / Electronic Shielding | Mu-metal Alloy + Polyimide (Kapton) | Protection against Electromagnetic Fields |

Parker Solar Probe (NASA):
Thermal Protection System (TPS): 4.5 in (11.43 cm) carbon-carbon (C-C) shield with a carbon foam core.
Solar array cooling system: radiators with ultrapure water and carbide plates.
Sun-facing side: coated with white alumina ceramic (Al_2O_3).



Technical Requirements
1. Vacuum and Extreme Temperature Resistance: The robot must be able to operate in vacuum conditions and extreme temperatures.
2. Propulsion and Navigation: The robot would need a propulsion and navigation system to move in space.
3. Welding System: The robot must have a welding system capable of welding metals in microgravity.
4. Manipulation System: The robot would need a manipulation system to handle materials and tools.
5. Control and Communication System: The robot must have a control and communication system to receive instructions and transmit data.

Technologies and Materials

1. Materials resistant to vacuum and extreme temperatures: Such as titanium, stainless steel, or composite materials.
2. Advanced Propulsion Systems: Such as ion engines or nuclear propulsion systems.
3. Advanced Welding Technologies: Such as laser welding or arc welding in microgravity conditions.
4. Robotic Manipulation Systems: Such as robotic arms or cable-based manipulation systems.

Steps to Build the Robot
1. Design and Simulation: Design and simulate the robot using computer-aided design (CAD) and simulation software.
2. Material and Component Selection: Select the appropriate materials and components for the robot.
3. Construction and Assembly: Build and assemble the robot.
4. Testing and Validation: Test and validate the robot under laboratory conditions and in space.

Challenges and Opportunities
1. Technical Challenges: Technical challenges include creating a welding system that works in microgravity and selecting appropriate materials.
2. Innovation Opportunities: Building a robot that can weld metals in space offers opportunities for innovation in areas such as robotics, welding, and space exploration.

It's important to note that building a robot that can weld metals in space is a complex and challenging project that requires the collaboration of experts in several fields.

METAL SECTION:
SHIELDS-COMPOSITES

Viscosity. As viscosity and its sensitivity to temperature (viscosity index) increase, fluidity decreases.
Surface tension. High surface tension in the liquid metal reduces its fluidity. For this reason, oxide films on the surface of the molten metal have a significant adverse effect on fluidity. For example, an oxide film on the surface of molten pure aluminum triples the surface tension.
Inclusions. Inclusions can significantly affect fluidity because they are insoluble. This effect can be verified by observing the viscosity of a liquid (such as oil) with or without sand particles; the liquid with sand has a higher viscosity and, therefore, lower fluidity.
Solidification pattern of the alloy. The manner in which solidification occurs (section 10.2) can affect fluidity. Furthermore, fluidity is inversely proportional to the solidification interval. The smaller the interval (as in pure metals and eutectics), the greater the fluidity. In contrast, alloys with longer solidification intervals (such as solid solution alloys) have lower fluidity.
The following casting parameters affect fluidity and can also affect the fluid flow and thermal characteristics of the system.
Mold design. The design and dimensions of the sprue, runners, and sprues affect fluidity.
Mold material and its surface characteristics. The higher the thermal conductivity of the mold and the rougher its surfaces, the lower the fluidity of the molten metal. Although heating the mold improves fluidity, it also slows the solidification of the metal. Consequently, the casting develops coarser grains and, consequently, lower strength.

Degree of superheat. Superheat (defined as the increase in temperature of an alloy above its melting point) improves fluidity by delaying solidification. Pouring temperature is often specified rather than the degree of superheat because it is more easily determined. Pouring speed. The slower the pouring speed of the molten metal into the mold, the lower the fluidity, because the cooling rate is greater when pouring slowly and the Heat transfer. This factor directly affects the viscosity of the liquid metal.

EXAMPLE 1.1 about the Solidification Times for Various Shapes Three metal pieces with the same volume but different shapes are being cast a sphere a cube and a cylinder with a height equal to its diameter Which of the pieces will solidify first and which will solidify the slowest Assume n Solution Consider the volume of each piece as unity Then from Equation 10.7 Solidification time r The surface areas are as follows

Variables: Sphere V a4 3 1 1Surface area22 bpr3 r a3 A 4pr2 4pa3 Cube Cylinder 4pb 2 3 4pb 1 3 4 84 V a3 a 1 and A 6a2 6 V pr2h 2pr3 r a1 2pb 1 3 A 2pr2 2prh 6pr2 6pa1 2pb 2 3

Therefore the respective solidification times are 5 54 thesphere 0 043C the cube 0 028C cylinder 0 033C

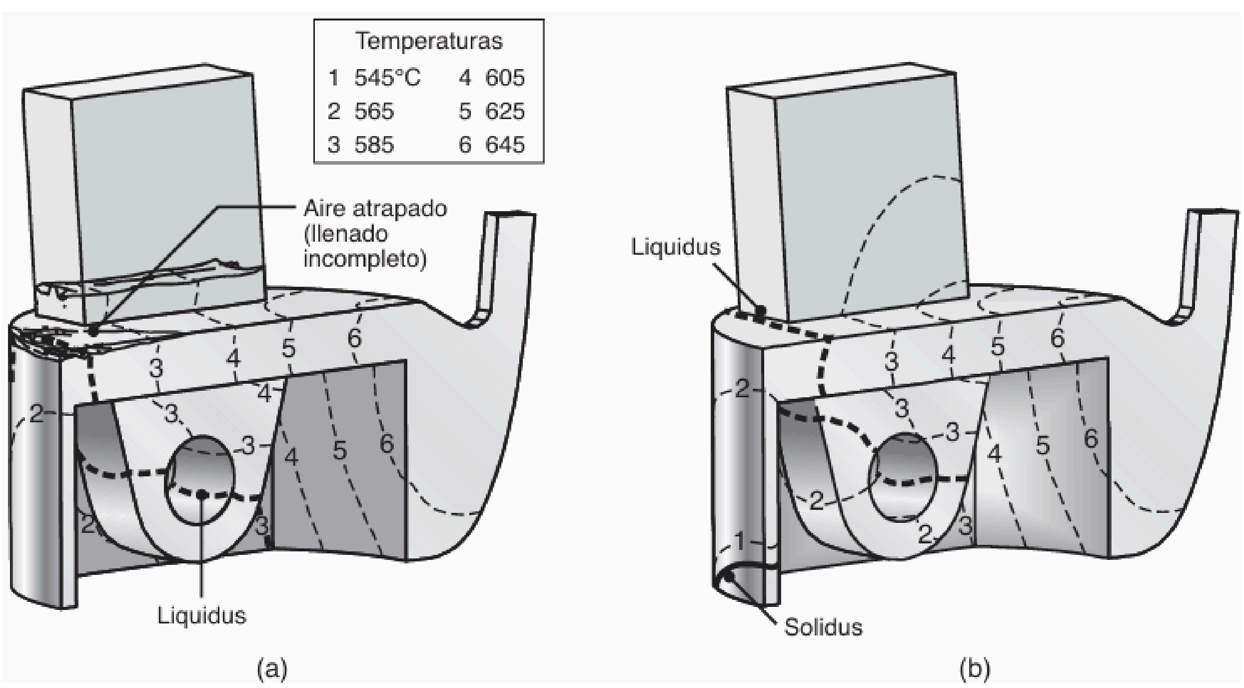
Then the cube shaped part will solidify faster and the spherical part will do so more slowly 10 5 2 Shrinkage Due to their thermal expansion characteristics metals in general contract compress during solidification and cool to room temperature Shrinkage which causes dimensional changes and sometimes cracking is the result of three consecutive events 1 Shrinkage of the molten metal as it cools before solidifying 2 Shrinkage of the metal during the phase change from liquid to solid latent heat of fusion 3 Shrinkage of the solidified metal the casting as its temperature is reduced to room temperature The greatest potential amount of shrinkage occurs when the casting cools to room temperature Table 10 1 shows the extent to which various metals shrink during solidification 10 6

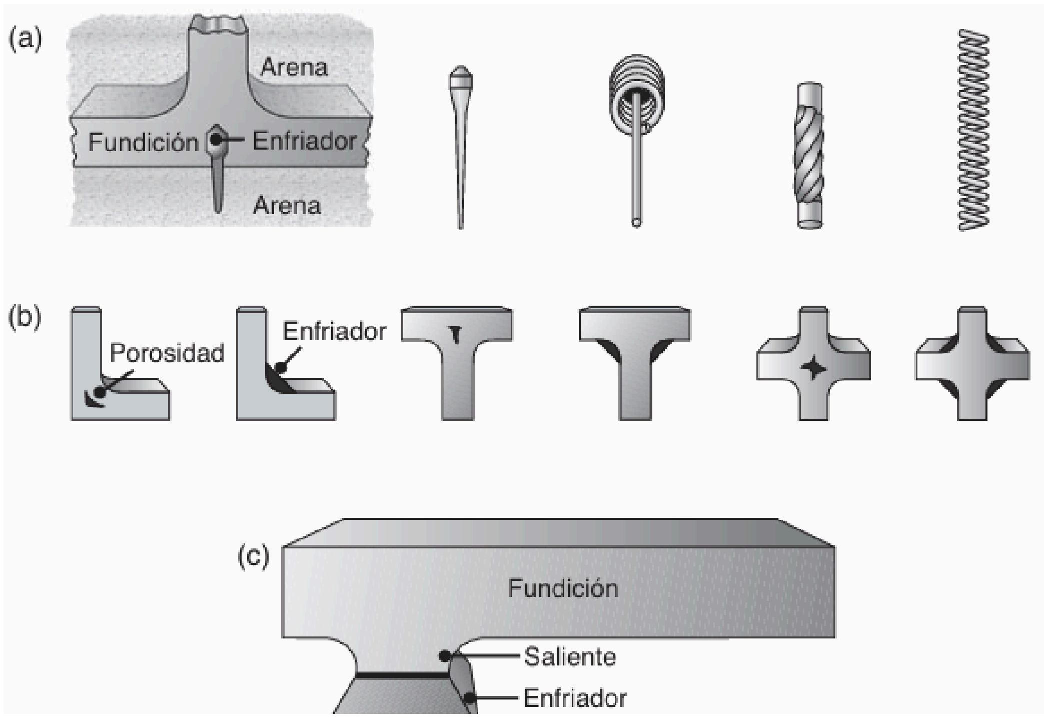
Defects 275 TABLE 10 1 Volumetric shrinkage or expansion upon solidification for various cast metals Shrinkage Expansion Aluminum Zinc Al 4 5 Cu Gold White iron Copper Bronze 70–30 Magnesium 7 1 6 5 6 3 5 5 4–5 5 4 9 4 5 4 2 90 Cu 10 Al Carbon steels 2 5

Script of the cylinder_sphere metal components:

```
import math

# Given volume for all shapes
V = 1

# Sphere
# V = (4/3)*pi*r^3 -> r = (3V/(4pi))^(1/3)
r_sphere = (3 * V / (4 * math.pi)) ** (1/3)
A_sphere = 4 * math.pi * r_sphere**2

# Cube
# V = a^3 -> a = V^(1/3)
a_cube = V ** (1/3)
```

```
A_cube = 6 * a_cube**2

# Cylinder (height = diameter = 2r)
# V = pi*r^2*h, h=2r -> V = 2*pi*r^3 -> r = (V/(2*pi))^(1/3)
r_cyl = (V / (2 * math.pi)) ** (1/3)
h_cyl = 2 * r_cyl
A_cyl = 2 * math.pi * r_cyl**2 + 2 * math.pi * r_cyl * h_cyl

# Assuming solidification time t ~ (V / A)^2 (from your note on eq. 10.7)
t_sphere = (V / A_sphere) ** 2
t_cube = (V / A_cube) ** 2
t_cyl = (V / A_cyl) ** 2

print(f"Sphere: Surface Area = {A_sphere:.4f}, Solidification Time =
{t_sphere:.4f}")
print(f"Cube: Surface Area = {A_cube:.4f}, Solidification Time =
{t_cube:.4f}")
print(f"Cylinder: Surface Area = {A_cyl:.4f}, Solidification Time =
{t_cyl:.4f}")

# Determine fastest and slowest solidification
times = {'Sphere': t_sphere, 'Cube': t_cube, 'Cylinder': t_cyl}
fastest = min(times, key=times.get)
slowest = max(times, key=times.get)

print(f"\nThe piece that solidifies first: {fastest}")
print(f"The piece that solidifies slowest: {slowest}")
```





Various types of chillers (a) internal and (b) external (dark areas in the corners) used in foundries to eliminate porosity caused by shrinkage. The chillers are placed in regions where there is a large volume of metal, as shown in (c).

- Hydrogen solubility
- Melting
- Melting point
- Temperature

Solubility of hydrogen in aluminum. Note the abrupt decrease in solubility as the molten metal begins to solidify.

Solid, Liquid interaction of the molten metal with the mold materials. Gases accumulate in areas where porosity exists (such as interdendritic regions) or cause microporosity in the casting, especially in cast iron, aluminum, and copper. Dissolved gases can be removed from the molten metal by washing or purging with an inert gas, or by melting and pouring the metal under vacuum. If the dissolved gas is oxygen, the molten metal can be deoxidized. In general, steel is deoxidized with aluminum, silicon, copper-based alloys with phosphorus copper, titanium, and zirconium.

Defects

It is difficult to determine whether microporosity is the result of contraction or caused by gases. If the porosity is spherical and has smooth walls (similar to the shiny holes in Swiss cheese), it is usually due to gases; but if the walls are rough and angular, it is likely due to contraction between dendrites. Coarse porosity is due to contraction and is commonly called a contraction cavity.

EXAMPLE 10.2 Casting Aluminum Automotive Pistons

Figure 10.16 shows an aluminum piston used in automotive internal combustion engines. These products can be manufactured at very high speeds, with tight dimensional tolerances and strict material requirements to ensure proper operation. Economic interests are obviously paramount, and it is critical that the pistons be produced with minimal costly finishing operations and very few rejected parts. Aluminum pistons are manufactured by casting due to their ability to produce near-net shapes at the required production speeds. However, poorly designed molds, incomplete fillings, or excessive porosity can lead to part rejection, which would increase costs. Traditionally, these defects were controlled through close machining tolerances, coupled with intuitive mold design based on experience. Pistons are produced with high-silicon alloys, such as aluminum alloy 413.0, which has high fluidity and can create high-resolution surfaces through permanent mold casting. It also has high corrosion resistance, good weldability, and low specific gravity. The universal acceptance of aluminum pistons for internal combustion engines is primarily due to its lightness and high thermal conductivity. Its reduced inertia allows for higher engine speeds and reduced counterweight on the crankshaft, while its higher thermal conductivity allows for more efficient heat transfer from the engine. The H13 tool steel mold is preheated from 200°C to 450°C, depending on the alloy to be cast and the size of the part.

Casting is a solidification process by which molten metal is poured into a mold and allowed to cool. The metal may flow through a variety of passages (pouring cups, sprues, runners, risers, and gates) before reaching the final mold cavity. Analytical tools used in casting design include Bernoulli's theorem, the law of mass continuity, and the Reynolds number, with the goals of obtaining an appropriate flow velocity and eliminating defects associated with fluid fluidity.

• Solidification of pure metals occurs at a constant temperature, while that of alloys occurs within temperature ranges. Phase diagrams are important tools for identifying the solidification point(s) of technologically important metals.

• The composition and cooling rates of the molten metal affect the size and shape of the grains and dendrites in the solidifying alloy. In turn, the size and structure of the grains and dendrites influence the properties of the solidified casting. Solidification time depends on the casting volume and surface area (Chvorinov's rule).

• The grain structure of castings can be controlled by various means to achieve desired properties. Because metals contract during solidification and cooling, cavities can form in the casting.
Porosity caused by gases released during solidification can be a significant problem, particularly due to its adverse effect on the mechanical properties of castings. Various defects may also occur in castings due to a lack of control over material and process variables.

• Although most metals contract during solidification, gray cast iron and some aluminum alloys actually expand. Dimensional changes and cracking (hot leafing) are difficulties that can arise during solidification and cooling. Seven basic categories of casting defects have been classified.

• Casting practices have the same direct effect on the quality of castings as foundry operations, such as production of designs and molds, pouring of molten metal, removal of castings from molds, cleaning, heat treatment, and inspection.

KEY TERMS

01. *Suction*
02. *Sprue*
03. *Feed Channels*
04. *Surface Layer*
05. *Gate*
06. *Shrinkage*
07. *Pouring Cup*
08. *Dendrites*
09. *Columnar Dendrites*
10. *Cored Dendrites*
11. *Coolers*
12. *Fluidity*
13. *Casting*
14. *Columnar Grains*
15. *Inoculant*
16. *Macrosegregation*
17. *Riser*
18. *Microsegregation*
19. *Mold*
20. *Heterogeneous Nucleation*
21. *Homogeneous Nucleation*
22. *Reynolds Number*
23. *Porosity*
24. *Freezing or Solidification Rate*
25. *Segregation*
26. *Feeding System*
27. *Solidification*
28. *Bernoulli's Theorem*
29. *Turbulence*
30. *Pasty Zone*

The casting process consists of these basic steps: (a) molten metal is poured into a mold in the shape of the part to be manufactured, (b) it is allowed to solidify, and (c) the part is removed from the mold. As with all other manufacturing processes, understanding the fundamentals of casting is essential to producing economical, high-quality castings, as well as establishing appropriate mold design techniques and practices.

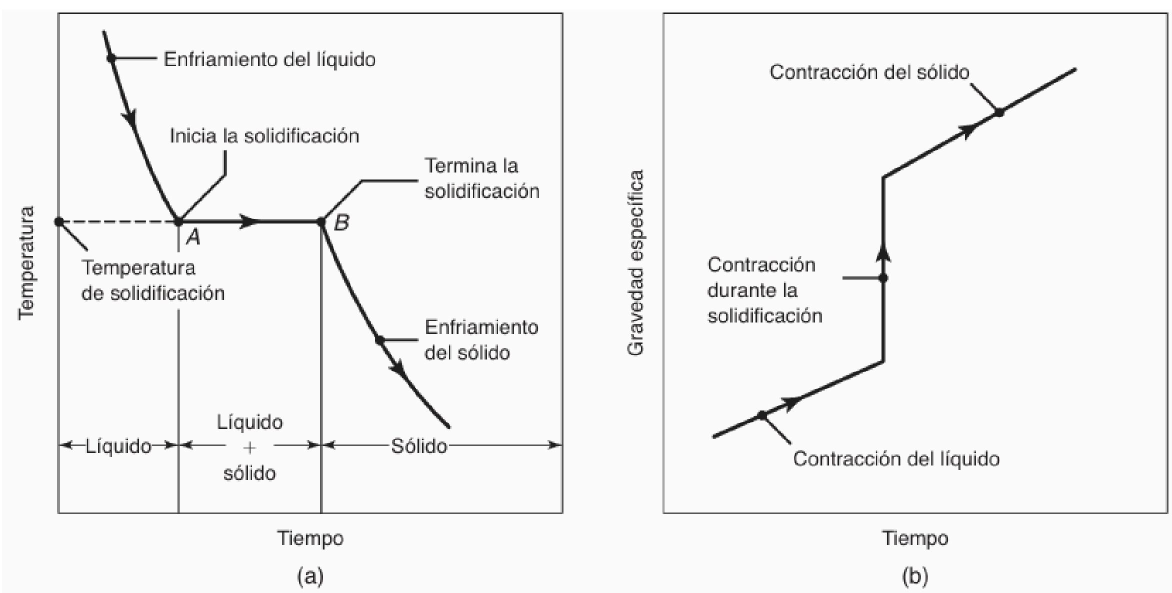
The following are important factors to consider in casting operations:

• The flow of molten metal within the mold cavity.

• The solidification and cooling of the metal within the mold.

• The influence of the type of mold material.
This chapter describes the relationship between the many factors involved in casting. First, the flow of molten metal within the mold cavity is analyzed in terms of mold design characteristics and fluid flow. The solidification and cooling of metals within the mold are affected by several factors, including the metallurgical and thermal properties of the metal. The type of mold is also important, as it affects the metal's cooling rate. Finally, the circumstances that influence the formation of defects are described.

Pure Metals
Because a pure metal has a clearly defined melting (or solidification) point, it solidifies at a constant temperature, as shown in Figure 10.1. For example, pure aluminum solidifies at 660°C (1220°F), iron at 1537°C (2798°F), and tungsten at 3410°C (6170°F). (See also Table 3.1 and Figure 4.4.) After the temperature of the molten metal drops to its solidification point, it remains constant while its latent heat of fusion dissipates. The solidification front (solid-liquid interface) moves through the molten metal from the mold walls toward the center. The solidified metal, called the casting, is removed from the mold and cooled to room temperature.



Key components modeled:
Material and thermal properties:

We define aluminum alloy 413.0, known for its high fluidity and mechanical properties.
We include melting temperatures and hydrogen solubilities in the liquid and solid phases.
Hydrogen solubility curve:
A curve is generated showing how the solubility drops sharply as the metal cools, which is key to predicting microporosity.

Defect diagnosis:
The difference in solubility is analyzed to predict the risk of microporosity ("Swiss cheese").
Casting system:
The design considers H13 steel molds (as used in engine pistons) and internal and external chillers to control shrinkage.

Diagnosis: High risk of microporosity → implies that degassing or vacuum evacuation techniques should be applied.

Visual curve: Clear evidence of phase change and hydrogen solubility drop.

Realistic simulation: Simple yet effective model that can be extended to carbon-carbon melting or inert atmosphere systems.

```
# Diseño básico en Python de un sistema de fundición para metales tipo
carbono-carbón en el espacio,
# considerando variables de temperatura, solubilidad, defectos y
simulación de enfriamiento.

import numpy as np
import matplotlib.pyplot as plt

# Propiedades de materiales típicos en fundición espacial
class Metal:
    def __init__(self, name, melting_point,
hydrogen_solubility_liquid, hydrogen_solubility_solid):
        self.name = name
        self.melting_point = melting_point  # °C
        self.hydrogen_solubility_liquid = hydrogen_solubility_liquid
# ppm
        self.hydrogen_solubility_solid = hydrogen_solubility_solid  #
ppm

    def solubility_curve(self, temperature):
        """Modelo simplificado de solubilidad del hidrógeno según la
fase"""
        if temperature > self.melting_point:
            return self.hydrogen_solubility_liquid
        else:
            return self.hydrogen_solubility_solid

# Ejemplo: Aleación de aluminio 413.0
al_413 = Metal("Aluminum Alloy 413.0", melting_point=570,
hydrogen_solubility_liquid=0.69, hydrogen_solubility_solid=0.04)

# Simulación del proceso de enfriamiento y cambio de solubilidad
def simulate_solidification(metal, start_temp, end_temp, steps=100):
```

```
    temps = np.linspace(start_temp, end_temp, steps)
    solubilities = [metal.solubility_curve(t) for t in temps]
    return temps, solubilities

# Modelo de enfriamiento y generación de defectos
def porosity_defect_estimator(solubility_liquid, solubility_solid):
    """Porosidad potencial por exceso de gas al solidificar"""
    delta_sol = solubility_liquid - solubility_solid
    if delta_sol > 0.5:
        return "High microporosity risk (Swiss cheese appearance)"
    elif delta_sol > 0.2:
        return "Moderate porosity, control degassing recommended"
    else:
        return "Low risk of porosity"

# Visualización de la curva de solubilidad
temps, sol = simulate_solidification(al_413, 700, 500)

plt.figure(figsize=(8, 4))
plt.plot(temps, sol, label=f"{al_413.name}")
plt.axvline(al_413.melting_point, color='red', linestyle='--',
label="Melting Point")
plt.title("Hydrogen Solubility vs Temperature")
plt.xlabel("Temperature (°C)")
plt.ylabel("Hydrogen Solubility (ppm)")
plt.legend()
plt.grid(True)
plt.tight_layout()
plt.show()

# Diagnóstico
diagnosis =
porosity_defect_estimator(al_413.hydrogen_solubility_liquid,
al_413.hydrogen_solubility_solid)
print("Defect Risk Diagnosis:", diagnosis)

# Componentes del sistema de fundición
class CastingSystem:
    def __init__(self, mold_material, use_internal_chillers=True):
        self.mold_material = mold_material
        self.use_internal_chillers = use_internal_chillers

    def describe(self):
        print(f"Mold material: {self.mold_material}")
        print("Chillers: ", "Internal and External" if
self.use_internal_chillers else "External only")
        print("Design focus: Avoid shrinkage porosity and promote
uniform solidification.")

# Crear un sistema de fundición ejemplo
foundry = CastingSystem("H13 Tool Steel", use_internal_chillers=True)
```

```
foundry.describe()
```