# A Solid Copper Cube Has An Edge Length Of 85.5 Cm. How Much Pressure Must Be Applied To Reduce This To

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When considering the compression of a solid copper cube, understanding the fundamental concepts of material properties, stress, strain, and the calculations involved is crucial. Copper, known for its excellent electrical conductivity and malleability, exhibits specific mechanical behaviors under applied forces. This article aims to explore the question: How much pressure must be applied to reduce a solid copper cube with an edge length of 85.5 cm to a smaller size? We will delve into the properties of copper, the physics behind compression, and the calculations required to determine the necessary pressure.

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## Understanding the Basics: Copper’s Material Properties

Before tackling the calculation, it's essential to understand the properties of copper relevant to compression and deformation.

### 1. Mechanical Properties of Copper

- Density: Approximately 8.96 g/cm³
- Young’s Modulus (Elastic Modulus): About 110 GPa (gigapascals)
- Yield Strength: Ranges from 33 MPa to 70 MPa depending on purity and processing
- Ultimate Tensile Strength: Around 210 MPa
- Poisson’s Ratio: Approximately 0.34

These properties influence how copper responds to applied stresses and strains, especially under compression.

### 2. Elastic vs. Plastic Deformation

- Elastic deformation: Reversible change in shape; occurs at stresses below the yield strength.
- Plastic deformation: Permanent change; occurs when stress exceeds the yield point.

The amount of pressure needed depends on whether the deformation is elastic or plastic. For significant size reduction, plastic deformation is usually necessary.

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# Calculating the Required Pressure for Size Reduction

To determine how much pressure is needed to compress the copper cube, we need to understand the relationship between stress, strain, and deformation.

## 1. Defining the Problem

Suppose the goal is to reduce the cube’s edge length from 85.5 cm to a smaller length (say, to a specific target). For this example, let's assume the target is to compress the cube to 80 cm, representing a specific percentage reduction.

Original edge length: 85.5 cm
Target edge length: 80 cm

Change in length ($\Delta L$): 85.5 cm - 80 cm = 5.5 cm

Strain ($\epsilon$):
$$
\epsilon = \frac{\Delta L}{L_0} = \frac{5.5\, \text{cm}}{85.5\, \text{cm}} \approx 0.0644
$$

This indicates about a 6.44% reduction in size.

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## 2. Calculating the Stress Using Young’s Modulus

Assuming elastic deformation for initial approximation (though significant deformation often involves plasticity):

$$
\sigma = E \times \epsilon
$$

Where:
- $\sigma$ = stress (pressure)
- $E$ = Young’s modulus (~110 GPa for copper)

- $\epsilon$ = strain (~0.0644)

Converting units:

$$
\sigma = 110\, \text{GPa} \times 0.0644 = 110 \times 10^9\, \text{Pa} \times 0.0644 \approx 7.084 \times 10^{9}\, \text{Pa}
$$

or about 7.084 GPa.

Important note: Since copper yields at much lower stresses (~33 MPa), elastic deformation at 7 GPa is unrealistic; the material would undergo plastic deformation well before reaching this stress. Therefore, plastic deformation considerations are more relevant.

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# Understanding Plastic Deformation and Yield Strength

To cause permanent deformation (size reduction), the applied stress must surpass the yield strength.

## 1. Yield Strength of Copper

- Typical values: 33 MPa to 70 MPa
- For safety, assuming an average yield strength of 50 MPa

## 2. Applying Plastic Deformation

- Once the stress exceeds yield strength, copper deforms plastically.
- To achieve a 6.44% reduction, a stress significantly above the yield point is typically required, depending on the material behavior and the form of deformation.

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# Estimating the Pressure Needed for Specific Size Reduction

Given that plastic deformation involves complex phenomena, including work hardening and strain rate effects, the exact pressure can vary. However, for estimation purposes:

Approximate pressure needed:
$$
\sigma_{plastic} \approx \text{a few times the yield strength}
$$

Suppose we consider applying a pressure of about 3 times the yield strength to ensure sufficient deformation:

$$
\sigma_{applied} \approx 3 \times 50\, \text{MPa} = 150\, \text{MPa}
$$

Thus, approximately 150 MPa of pressure might be required to plastically deform the copper cube enough to reduce its size by about 6.4%.

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# Additional Factors Influencing the Compression Process

The amount of pressure needed is influenced by several other factors:

## 1. Uniformity of Force Distribution

- Ensuring even pressure across the entire surface prevents uneven deformation or cracking.

## 2. Temperature Effects

- Elevated temperatures can lower yield strength, making deformation easier.
- Hot working processes utilize this principle to reduce required pressures.

## 3. Strain Rate

- Faster deformation may require higher pressures due to strain rate sensitivity.

## 4. Material Purity and Grain Structure

- Purity and grain size can influence mechanical properties and deformation behavior.

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# Practical Methods for Applying Pressure to Copper

To achieve the calculated pressures, specific techniques and equipment are used:

## 1. Hydraulic Presses
- Capable of exerting hundreds of MPa.
- Suitable for controlled compression of metal blocks.

## 2. Forge Presses and Hot Working
- Applying heat reduces the necessary force.
- Hot working is common for shaping copper.

## 3. Explosive Compression
- Used in scientific research for achieving ultra-high pressures.

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# Summary of Key Points

- To compress an 85.5 cm copper cube to a smaller size, significant pressure is required.
- Elastic deformation alone requires stresses on the order of several gigapascals (~7 GPa), which is impractical and beyond copper's elastic limit.
- Permanent size reduction involves plastic deformation, which can be achieved at stresses around 150 MPa or higher.
- Practical compression involves applying uniform, controlled pressure via industrial equipment, often combined with heat to facilitate deformation.
- Exact pressure depends on the degree of size reduction, temperature, and material properties.

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# Conclusion

Reducing a solid copper cube with an edge length of 85.5 cm involves understanding the interplay between material properties, deformation mechanics, and applied forces. While elastic deformation requires extremely high stresses, practical size reduction is achieved through plastic deformation at manageable pressures, typically in the range of 150 MPa or more. Industrial techniques such as hot pressing, forging, or hydraulic pressing are used to apply such pressures effectively. Understanding these principles is essential for engineers and material scientists working on metal shaping, manufacturing, and materials testing.

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# FAQs About Compressing Copper and Material Deformation

- **Q:** Can copper be compressed to half its size?
- **A:** Yes, but it requires applying stresses well above its yield strength, and the process may involve plastic deformation, heat treatment, and specialized equipment.
- **Q:** Is it possible to reduce the size of a copper cube without breaking it?
- **A:** Yes, with controlled compression and appropriate temperature management, copper can be deformed plastically without fracturing.
- **Q:** How does temperature influence the compression of copper?
- **A:** Elevated temperatures decrease copper's yield strength, making it easier to deform under lower pressures.

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By understanding the mechanics behind material deformation and applying the correct calculations, engineers can determine the approximate pressure needed to shape copper and other metals for various applications.

# Frequently Asked Questions

## What is the primary factor determining the pressure needed to compress a solid copper cube?

The primary factor is the compressive strength or yield strength of copper, which indicates how much pressure is required to cause deformation or reduction in size.

## How do you calculate the force needed to compress the copper cube?

You calculate the force by multiplying the desired pressure (in Pascals) by the cross-sectional area of the cube's face: Force = Pressure × Area.

## What is the approximate compressive strength of copper, and how does it relate to the pressure required?

The typical compressive strength of copper is around 210 MPa (megapascals). To reduce the cube, the applied pressure must at least match or exceed this value depending on the deformation goal.

## How does the edge length of 85.5 cm affect the calculation of the pressure needed?

The edge length determines the surface area (A = edge length$^2$), which is used to calculate the force required when applying a certain pressure. Larger cubes require proportionally larger forces for the same pressure.

## What safety considerations should be taken into account when applying high pressure to copper?

High-pressure application involves risks such as equipment failure or material fracture. Proper safety gear, calibrated equipment, and adherence to safety protocols are essential to prevent accidents.

# Additional Resources

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Introduction

The question of how much pressure is necessary to compress a solid copper cube from its original dimensions to a significantly smaller size touches on fundamental principles of materials science, physics, and engineering. Copper, known for its excellent electrical conductivity, ductility, and relatively high malleability, is often used in applications where deformation under stress is routine. However, understanding the limits of its deformation—specifically, the amount of pressure needed to reduce a solid copper cube from a given size—is critical for designing equipment, predicting failure modes, and exploring the material's behavior under extreme conditions.

This article aims to thoroughly investigate the question: How much pressure must be applied to reduce a copper cube with an initial edge length of 85.5 cm to a smaller size? We will explore the fundamental concepts involved, including elastic and plastic deformation, yield strength, ultimate tensile strength, and the mechanics of compression. Additionally, we will examine the relevant calculations, assumptions, and real-world considerations that influence the amount of pressure required for such a transformation.

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Understanding the Material: Copper's Mechanical Properties

To assess the pressure needed to compress the copper cube, it is essential to understand the physical and mechanical properties of copper.

Basic Properties of Copper

- Density: Approximately 8.96 $g/cm^3$
- Yield Strength: Typically around 33 MPa (megapascals) for commercial purity copper, though this can vary based on purity, processing, and alloying.
- Ultimate Tensile Strength (UTS): Around 210 MPa
- Elastic Modulus (Young's modulus): Approximately 110 GPa
- Ductility: Very ductile; can sustain significant plastic deformation before fracture.

The yield strength indicates the stress at which copper begins to deform plastically, i.e., permanent deformation occurs. To cause a meaningful reduction in size, the applied pressure must at least surpass this threshold, but the actual pressure needed depends on the nature and extent of deformation desired.

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Theoretical Framework for Compression

Elastic vs. Plastic Deformation

- Elastic deformation is reversible; the material returns to its original shape once the load is removed.
- Plastic deformation is permanent; the material undergoes a permanent change in shape or size.

For significant size reduction, the copper must undergo plastic deformation, which requires surpassing its yield strength.

Calculating the Force from Stress

Stress ($\sigma$) is defined as force (F) divided by the cross-sectional area (A):

$$\sigma = \frac{F}{A}$$

To induce a certain stress, the applied force must be:

$$ F = \sigma \times A $$

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Step 1: Determining the Target Reduction

Suppose the goal is to reduce the cube’s edge length from 85.5 cm to a smaller value—say, 60 cm. This would involve:

- Initial volume:

$$ V_i = (85.5\, \text{cm})^3 = 85.5^3 \approx 624,508\, \text{cm}^3 $$

- Final volume:

$$ V_f = (60\, \text{cm})^3 = 216,000\, \text{cm}^3 $$

- Volume change:

$$ \Delta V = V_i - V_f \approx 624,508 - 216,000 = 408,508\, \text{cm}^3 $$

- Percent volume reduction:

$$ \frac{\Delta V}{V_i} \times 100 \approx \frac{408,508}{624,508} \times 100 \approx 65.4\% $$

This is a substantial volume reduction, implying significant plastic deformation.

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Step 2: Strain and Stress Considerations

Calculating the Strain

Assuming uniform compression:

$$ \text{Linear strain} \ ( \varepsilon ) = \frac{\Delta L}{L_0} $$

where $L_0 = 85.5\, \text{cm}$, and $\Delta L = 85.5\, \text{cm} - 60\, \text{cm} = 25.5\, \text{cm}$.

$$ \varepsilon = \frac{25.5}{85.5} \approx 0.298 \ (29.8\%) $$

This represents a nearly 30% reduction in length, which is significant and well into the plastic deformation regime.

Corresponding Stress

Since copper's yield strength is about 33 MPa, the applied pressure must at least reach this level to initiate plastic deformation.

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Step 3: Calculating the Required Force

- Cross-sectional area of the face being compressed:

$$ A = (85.5\, \text{cm})^2 = 85.5^2 \approx 7308\, \text{cm}^2 $$

- Force to reach yield stress:

$$ F_{yield} = \sigma_{yield} \times A = 33\, \text{MPa} \times 7308\, \text{cm}^2 $$

Convert units:

- $1\, \text{MPa} = 10^6\, \text{N/m}^2$
- $1\, \text{cm}^2 = 10^{-4}\, \text{m}^2$

Therefore,

$$ F_{yield} = 33 \times 10^6\, \text{N/m}^2 \times 7308 \times 10^{-4}\, \text{m}^2 $$

$$ F_{yield} = 33 \times 10^6 \times 0.7308\, \text{m}^2 $$

$$ F_{yield} \approx 24,112,400\, \text{N} $$

This force (~24 million newtons) is the approximate load needed to just surpass the yield strength under uniform compression.

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Step 4: Considering Real-World Factors

The enormous magnitude of the force indicates the practical challenges involved. Several factors influence the actual pressure required:

- Stress Concentrations: Real materials have imperfections, leading to localized stress concentrations that can cause deformation at stresses lower than the theoretical yield strength.
- Friction and Contact Mechanics: Friction between the pressing apparatus and the copper surface increases the actual force required.
- Strain Rate Effects: Higher deformation rates can influence the stress-strain response.
- Temperature: Elevated temperatures can lower the yield strength, reducing the force needed.

In practical terms, applying nearly 24 million newtons of force to a 85.5 cm cube is infeasible with conventional equipment. The process would require specialized high-pressure apparatus, such as massive hydraulic presses or explosive compaction methods.

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Step 5: Plastic Deformation and Pressure Beyond Yield

To achieve a significant reduction in size, the copper must undergo plastic deformation well beyond the yield point. The flow stress (the stress required to continue plastic deformation) is often higher than the yield strength, especially for large strains.

Assuming strain hardening, the flow stress can be approximated as:

$$ \sigma_{flow} = \sigma_{yield} \times (1 + k \varepsilon^n) $$

where $k$ and $n$ are material-specific constants. For copper, typical values are:

- $k \approx 0.002$ (unitless)
- $n \approx 0.3$

Given the large strain (~0.3), the flow stress could be roughly:

$$ \sigma_{flow} \approx 33\, \text{MPa} \times (1 + 0.002 \times 0.3^{0.3}) $$

The correction is minor; thus, the actual stress needed for large plastic strains might be on the order of 35-40 MPa, slightly higher than the yield strength.

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Deep-Dive: Practical Limits and Material Behavior Under Extreme Pressure

While the calculations above provide theoretical minimums, real-world applications confront various limitations:

- Material Fracture: Copper may crack or fracture if subjected to stresses exceeding its ultimate tensile strength (~210 MPa), especially if imperfections exist.
- Equipment Limitations: No conventional press can generate forces in the tens of millions of newtons on such a scale.
- Energy Requirements: The energy needed to generate and sustain such enormous force is prohibitive.

Real-World Examples and Analogies

- Hydraulic Press Capabilities: Industrial hydraulic presses typically operate up to 1000 MPa but are limited in size and force capacity.

- Explosive Compaction: Techniques like explosive welding or powder compaction can generate very high pressures locally, but these are specialized processes.

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Final Considerations: Theoretical vs. Practical

Theoretically, to compress a copper cube from 85.5 cm to a significantly smaller size, you would need to apply a pressure exceeding its yield strength, roughly in the tens of megapascals, scaled by the degree of deformation desired. However, the actual pressure required to produce a substantial, permanent size reduction, especially in a solid monolithic piece, approaches or exceeds hundreds of megapascals, potentially into the gigapascal range, considering strain hardening, friction, and other real-world factors.

In summary:

- Minimum pressure to initiate plastic deformation: On the order of 33 MPa
- Pressure for significant size reduction

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