Influence Of Cryogenics on Materials

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Definition

Cryogenics is the process of subjecting a material to below freezing temperatures to achieve new or various properties of the materials.

Figure 1. Container of Liquid Nitrogen, a common coolant for cryogenics

Procedure

Superconducting Magnet tests were done using samples at room temperature (293K or 68 °F) and samples removed from cryogenic cooling (77K or -321 °F).
3 types of tests were performed.

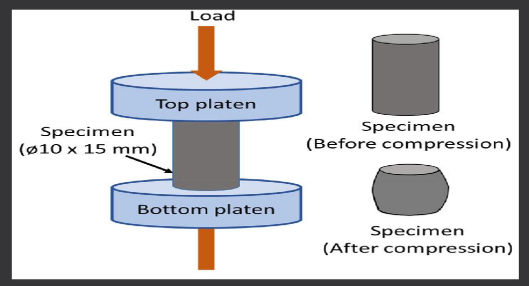


Figure 2. Compression Test Diagram

- Compression – Exerting forces into the sample until failure occurs.
- Tensile – Pulling a sample apart until failure occurs.
- Shear – Exerting two forces in opposite directions until failure occurs.

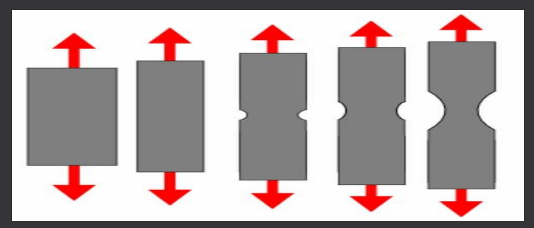


Figure 3. Tensile Test Diagram

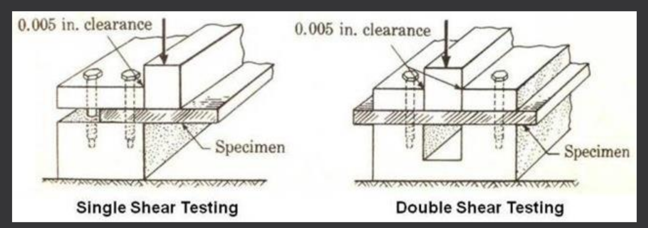
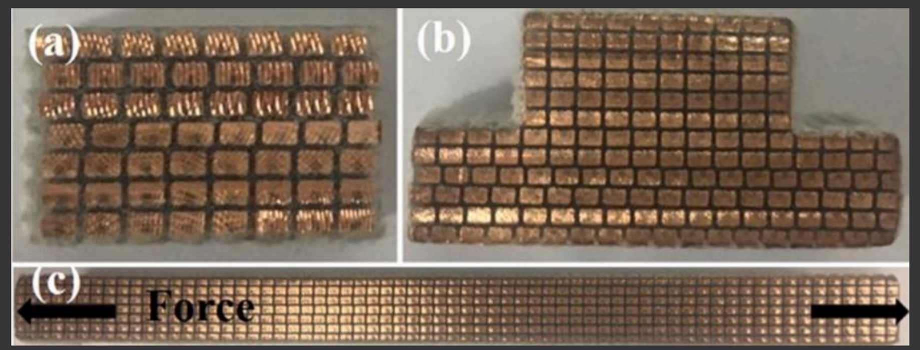


Figure 4. Shear Test Diagram



Superconductor specimen for a) Compression, b) Shear, and c) Tensile

Concrete tests were performed using 2 total variations of samples. These samples would go under increasingly colder temperatures before the compression tests occurs.

- Moist – Concrete that receives water after the cement mixing process finishes.
- Air-dry – Concrete that does not receive water after the cement mixing process finishes.

Figure 5. Concrete cylinder that would undergo compression testing

Aluminum 7050 undergoes 3 different processes, but in various order to investigate any differences in results.

- Single Solution (S) – Samples were heated to 738K for 1 hour, then brought to room temperature by being soaked in water.
- Aging Treatment (A) – Samples were heated to 393K held for 20 hours and then cooled down by air-drying.
- Deep Cryogenic Treatment (C) – Samples were cooled down to 77 K, soaked for 12 hours in liquid nitrogen, and then rewarmed to room temperature.

Table 1. The different order of treatments samples of Aluminum 7050 underwent. (Weng 2021)

Treatment groups with different combination of solution, aging, and deep cryogenic treatment	
Index	Order of Treatments
S	Single Solution Treatment
SC	Single-Deep Cryogenic Treatment
SA	Single-Aging Treatment
SCA	Single-Deep Cryogenic-Aging Treatment
SAC	Single-Aging-Deep Cryogenic Treatment

Results

The results look upon various properties of each material. The superconducting magnet and concrete focus on the strength of the material, while the aluminum focuses on thermal conductivity.

a) Superconducting Magnet (MRI)

Mechanical Properties	Room Temperature	77K
Tension Strength (Mpa)	8.1 ± 1.1	6.9 ± 0.3
Radial Shear Strength (Mpa)	19.1 ± 1.4	31.2 ± 2.4
Axial Shear Strength (Mpa)	12.6 ± 0.8	21.4 + 1.7
Radial Compressive Strength (Mpa)	117.1 ± 1.5	271.1 ± 5.0
Axial Compressive Strength (Mpa)	106.7 ± 1.0	287.9 ± 4.5

Table 2. A table of the force capacities of the superconducting magnet. (Wentao 2021)

When undergoing the cryogenic process, the superconducting magnet increases in both shear and compressive by twice or more than that of the room temperature samples. On the other hand, the tensile strength takes a slight reduction in maximum capacity.

b) Concrete

Concrete gains more compressive strength for both dry and moist samples, but the moist samples benefit much more than the dry samples. However, if concrete goes through rapid freezing and thawing too much, it will begin to form cracks, lowering the strength.

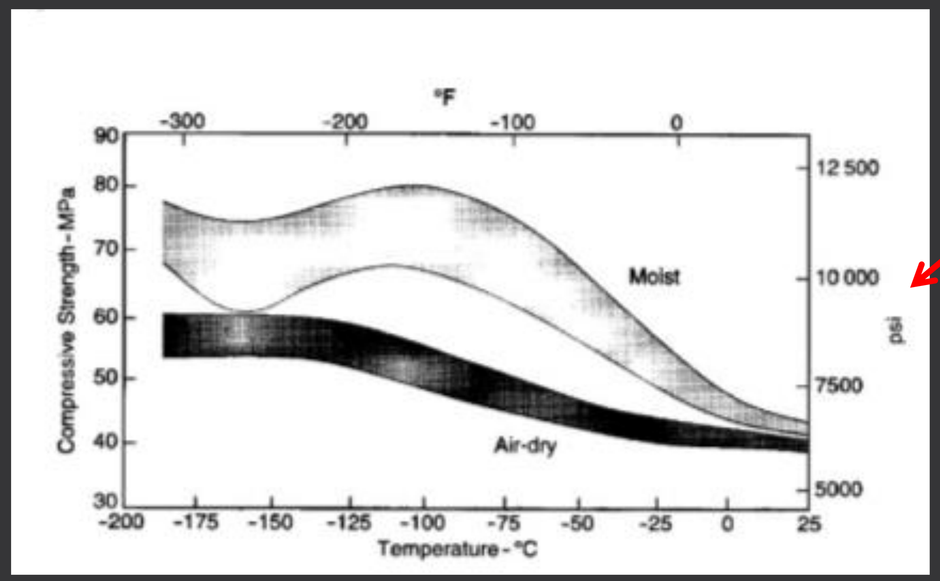


Figure 6. Compressive strength of concrete over various temperatures between moist samples and air-dried samples

c) Aluminum 7050

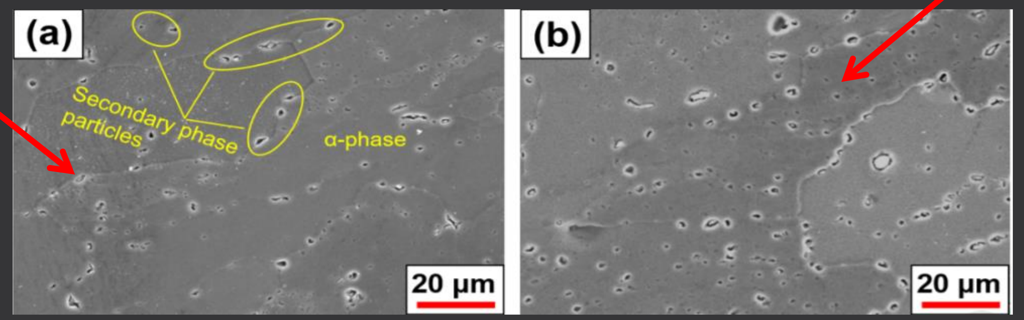


Figure 7. Picture of the microstructures of (a) Single Solution sample vs (b) Single Cryogenic sample. (Weng 2021)

After examining both pictures, the Single Cryogenic sample has more precipitate than the Single Solution sample, indicating the cryogenic process affects the microstructure. This extra precipitate is responsible for the loss of thermal conductivity in the aluminum.

Summary

This research indicates that cryogenics affects the material behavior in many ways. For example, the superconducting magnet and concrete gains compressive strength up to 3 times larger than that of room temperature, and Aluminum will lose thermal conductivity when undergoing the cryogenic process. The benefit of this research aids in many fields such as hospitals with improving MRI machines. In terms of engineering, the properties of concrete are being investigated to replace the use of steel in liquid natural gas (LNG) storage tanks to reduce costs of projects.

References

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