COMPARATIVE STUDY OF THERMAL CONDUCTIVITY OF COPPER, ALUMINIUM AND STEEL

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(Creating the community of Excellence)

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ABSTRACT

Thermal Conductivity is an important material property in industry and daily situations like knowing what to choose in cookware or to determine what we use to keep warm or cool and protects us from heat or cold. In this experiment, I made a simple set-up to observe the change in heat flow and evaluate how thermal conductivity varies in different types of metals. The tests were done with copper, aluminum metal and steel alloy strips.

For my research I cut each metal and alloy strip into 15 cm, 30 cm and 45 cm strip and made three bridges each such as 1-fold bridge, 2-fold bridge and 3-fold bridge. For this science fair project, the independent variable is the type of metals and alloy strip used – copper, aluminum and steel. The dependent variable is the temperature difference. This is determined by using the laboratory thermometer to measure the temperature of the hot and cold water. The constants (control variables) are the length and diameter of the strips, the temperature of the water, amount of water, dipping area of the strips and the distance between the measurements.

Thermal conductivity was measured by observing the temperature difference both in the hot and cold water cups in which the metal and alloy bridges are immersed for heat transfer. Through my investigation I found copper has the highest heat conductivity value, followed by aluminum while steel which is the alloy of carbon and iron has the lowest heat conductivity value. I found that as the fold increases the rate of change in temperature also increases in all the metal bridges. Conduction happens best when more molecules are in contact with each other. Folding the metal bridges in half twice allows the heat from the hot cup to travel through more molecules, allowing more heat to travel from the hot cup to the cold cup.



INTRODUCTION

There are so many types of materials in the environment but if we take a good look around our homes, our schools, our community and the whole environment we would see that there is this material that is very hard, very strong, it does not break easily, it usually has a shiny surface, it is heavy, it is able to carry heat and electricity. Examples of items that are made out of this material are spoons, nails, cutlasses, cooking pots etc. This material is called a metal. However, there is another material around us that is just the opposite of metals. They break easily, they do not have a shiny surface, they do not carry heat and electricity well etc. Examples of items made out of this material are wood, plastic, paper, rubber etc. This other material is called a non-metal.

Metal Physical Properties:

- Lustrous (shiny)
- Good conductors of heat and electricity
- High melting point
- High density (heavy for their size)
- Malleable (can be hammered)
- Ductile (can be drawn into wires)
- Usually solid at room temperature (an exception is mercury)
- Opaque as a thin sheet (can't see through metals)
- Metals are sonorous or make a bell-like sound when struck

Nonmetal Physical Properties:

- Not lustrous (dull appearance)
- Poor conductors of heat and electricity
- Non-ductile solids
- Brittle solids
- May be solids, liquids or gases at room temperature
- Transparent as a thin sheet
- Nonmetals are not sonorous

Alloys

Alloys are mixtures of two or more different metals or of a metal and non-metal. Alloys are formed in order to improve the properties of a metal. This is because the various metals or non-metals that will be mixed have different properties and all those properties will benefit when they are mixed together to form alloys.

Examples of alloys, their composition and their use

ALLOY	COMPOSITION	USES
Bronze	Copper and Tin	Used for making statues & medals, coins and bells.
Brass	Copper and Zinc	Used for making statues & medals, jewels, musical instruments.
Steel	Carbon and Iron	Used for making car and machine parts.
Duralumin	Aluminium and Copper	Used for constructing aircraft.
Solder	Lead and Tin	Used for joining electrical components.

Importance of Alloys

- They have higher tensile strength.
- They are cheaper and have more uses.
- They are less likely to rust e.g. Steel.

Thermal Conductivity

Thermal conductivity measures the ability of a metal to conduct heat. The transfer of thermal energy from a warmer area to a cooler area is called thermal conduction. The rate at which thermal energy is being transferred is called thermal conductivity. Thermal energy is always transferred from a warmer to a cooler area. Thermal conduction can also occur between two different objects that touch each other.

The thermal conductivity of a material is highly dependent on composition and structure. Generally speaking, dense materials such as metals and stone are good conductors of heat, while low density substances such as gas and porous insulation are poor conductors of heat. This property varies across different types of metal and is important to consider in applications where high operating temperatures are common. In pure metals, thermal conductivity stays roughly the same with increases in temperature. However in alloys the thermal conductivity increases with temperature.

Here are some important applications which require metals that conduct heat well:

- Heat Exchangers
- Heat Sinks
- Cookware

Heat Exchangers

A heat exchanger is a common application where good thermal conductivity is important. Heat exchangers do their job by transferring heat to achieve heating or cooling.

Copper is a popular choice for heat exchangers in industrial facilities, air conditioning, refrigeration, hot water tanks and under-floor heating systems. Its high thermal conductivity allows heat to pass through it quickly. Copper has additional properties desirable in heat exchangers including resistance to corrosion, biofouling, stress and thermal expansion.

Aluminum can also be used in some heat exchanger applications as a more cost-effective alternative.

Heat exchangers are commonly used in the following situations:

Industrial Facilities

Heat exchangers in industrial facilities include fossil and nuclear power plants, chemical plants, desalination plants and marine services.

In industrial facilities copper-nickel alloy is used to construct the heat exchanger tubing. The alloy has good corrosion resistance which protects against corrosion in saltwater environments. It also has good biofouling resistance to avoid formation of algae and sea mosses. Aluminum-brass alloy has similar properties and can be used as an alternative.

Solar Thermal Water Systems

Solar water heaters are a cost-effective way to heat water in which a copper tube is used to transfer the solar thermal energy to the water. Copper is used because of copper's high thermal conductivity, resistance to air and water corrosion, and mechanical strength.

Gas Water Heaters

Gas water heat exchangers transfer the heat generated by gas fuels to water. They're common in residential and commercial boilers. For gas water heaters, copper is the preferred material because of its high thermal conductivity and ease of fabrication.

Forced Air Heating and Cooling

Heat pumps using air have long been used for residential and commercial heating. They work via air-to-air heat exchange through evaporator units. They can be used in wood furnaces, boilers, and stoves. Again, copper is typically used for its high thermal conductivity.

Heat Sinks

Heat sinks are a type of heat exchanger that transfers heat generated by an electronic or mechanical device into a moving coolant fluid. The fluid transfers the heat away from the device, allowing it to cool to the desired temperature. Metals with high thermal conductivity are used. Computers use heat sinks to cool central processing units or graphics processors. Heat sinks are also used in high power devices like power transistors, lasers and light emitting diodes (LEDs). Heat sinks are designed to maximize the surface area in contact with the coolant fluid. Aluminum alloys are the most common heat sink material. This is because aluminum costs less than copper. However copper is used where higher levels of thermal conductivity are needed. Some heat sinks use a combination aluminum fins with a copper base.

Cookware

A more household use of metal with good thermal conductivity is in cookware. When you're heating up your food, you don't want to wait all day. That is why copper is used in the bottoms of high-quality cookware because the metal rapidly conducts the heat and spreads it evenly across its surface. However, if you're on a budget you can use aluminum cookware as an alternative. It may take a little longer to heat up your food, but your wallet will thank you for it!

STATEMENT OF THE PROBLEM

Although all metals are good heat conductors, they are not heat conductive at the same rate. Some metals are simply a better heat conductor than others. For safety and energy conservation reasons we may want to use metals that are not good heat conductors. Knowing the heat conductivity of different metals can help us in selecting the right metal for different uses. So in this project I planned to compare copper, aluminium and steel to see which conducts heat best.

HYPOTHESIS

Copper is the best thermal conductivity metal when compared with aluminium and steel.

DESIGN OF STUDY

INDEPENDENT VARIABLE:

- Types of Metals (Copper and Aluminium) and Alloy (Steel)

DEPENDENT VARIABLE:

- Change in temperature (Both hot and cold)

CONTROLLED VARIABLES:

- Dimensions of metals and alloy
- Dipping area of metals and alloy
- Amount of water
- Size and nature of cup

MATERIALS NEEDED:

- Copper, Steel, Aluminium strips of same thickness.
- 32 identical cups
- Stove to boil water in a container
- 16 thermometers
- A large container that will fit in the refrigerator
- Water
- Notebook and pen

PROCEDURE:

1. Cut the metals and alloy strips into 15 cm, 30 cm and 45cm each.
2. Make 15 cm as 1-fold bridge, 30 cm as 2-fold bridge and 45 cm as 3-fold bridge.
3. Take 15 pairs of cups and label as copper 1-fold, copper 2-fold and copper 3-fold and so on for other metals.
4. One pair of cups will have no bridges. This is the control group.
5. Place the metal bridges in respective cups.
6. Place the thermometers in each of the cups that will hold cold water.
7. Boil some water. Let it cool a bit before use.

8. For each pair of cups, pour equal volumes for hot water into the “hot” cup. Be sure the water covers the ends of the bridges.
9. For each pair of cups, pour equal volumes of cold water into the “cold” cup. Be sure the water covers the end of the bridges.
10. Take the initial temperature of hot water and cold water. Record the temperature in a chart listing the time (in minutes) and temperature (in degrees Fahrenheit).
11. Record the temperature of each cold water cup every 5 minutes for a total of 30 minutes.
12. Which cup of cold water experienced the greatest change in temperature from the beginning to the end? Calculate this by subtracting the cups starting temperature from its final temperature.
13. Organize data with graphs. On the x-axis, plot time in minutes. On the y-axis, plot temperature difference in degrees. By creating a chart like this, we can see which metal transfers the most heat overall. This also gives us some information about each metal’s conductivity: The steeper the slope, the higher the conductivity.

COLLECTION OF DATA

PHOTOGRAPHS

TABULATION

THERMAL CONDUCTIVITY OF COPPER

Time (Minutes)	CONTROL		1-fold metal bridge		2-fold metal bridge		3-fold metal bridge	
	Temperature of Hot water (°C)	Temperature of Cold water (°C)	Temperature of Hot water (°C)	Temperature of Cold water (°C)	Temperature of Hot water (°C)	Temperature of Cold water (°C)	Temperature of Hot water (°C)	Temperature of Cold water (°C)
0	77	8	77	8	77	8	77	8
5	65	10	66	8.5	65	9	64	11
10	58	12	58	10.5	57	11	56	13
15	53	14	53	13	52	15	51	16
20	49	16	49	16	48	17	46	18
25	46	19	45	18	44	19	43	21
30	43	19	43	19	42	21	41	23

THE EFFECT OF COPPER IN HEAT TRANSFER

	Initial Temperature (°C)	Final Temperature (°C)	Changes in Temperature (°C)
Control-Hot	77	43	34
1-fold metal bridge-Hot	77	43	34
2-fold metal bridge-Hot	77	42	35
3-fold metal bridge-Hot	77	41	36
Control-Cold	8	19	11
1-fold metal bridge-Cold	8	19	11
2-fold metal bridge-Cold	8	21	13
3-fold metal bridge-Cold	8	23	15

THE THERMAL CONDUCTIVITY OF ALUMINIUM

Time (Minutes)	CONTROL		1-fold metal bridge		2-fold metal bridge		3-fold metal bridge	
	Temperature of Hot water (°C)	Temperature of Cold water (°C)	Temperature of Hot water (°C)	Temperature of Cold water (°C)	Temperature of Hot water (°C)	Temperature of Cold water (°C)	Temperature of Hot water (°C)	Temperature of Cold water (°C)
0	74	8	74	8	74	8	74	8
5	63	11	64	11	63	11	62	12
10	56	13	57	13	56	14	55	14
15	49	16	50	16	48	16	47	18
20	44	18	45	18	43	18	43	20
25	42	19	43	20	41	20	41	21
30	40	20	41	21	39	21	39	22

THE EFFECT OF ALUMINIUM IN HEAT TRANSFER

	Initial Temperature (°C)	Final Temperature (°C)	Changes in Temperature (°C)
Control-Hot	74	40	34
1-fold metal bridge-Hot	74	41	33
2-fold metal bridge-Hot	74	39	35
3-fold metal bridge-Hot	74	39	35
Control-Cold	8	20	12
1-fold metal bridge-Cold	8	21	13
2-fold metal bridge-Cold	8	21	13
3-fold metal bridge-Cold	8	22	14

THE THERMAL CONDUCTIVITY OF STEEL

Time (Minutes)	CONTROL		1-fold metal bridge		2-fold metal bridge		3-fold metal bridge	
	Temperature of Hot water (°C)	Temperature of Cold water (°C)	Temperature of Hot water (°C)	Temperature of Cold water (°C)	Temperature of Hot water (°C)	Temperature of Cold water (°C)	Temperature of Hot water (°C)	Temperature of Cold water (°C)
0	70	5	70	5	69	5	69	5
5	61	7	61	7	60	7	59	7
10	55	9	56	10.5	54	11	53	10
15	49	13	50	12	49	14	48	13.5
20	44.5	15	46	16	45	15	44	15
25	42	16	44	17	43	18	22	17
30	40	18	41	18	42	22	39	18

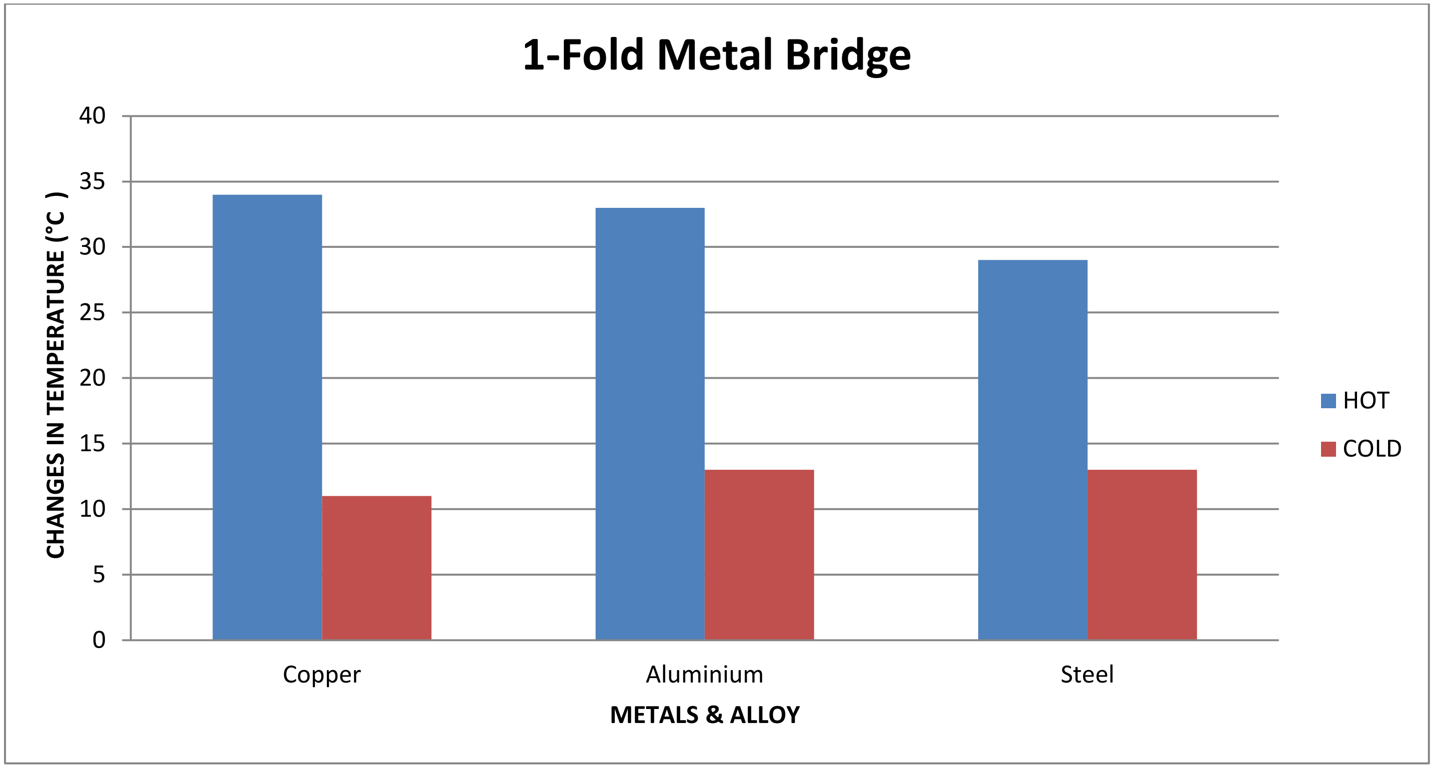
THE EFFECT OF STEEL IN HEAT TRANSFER

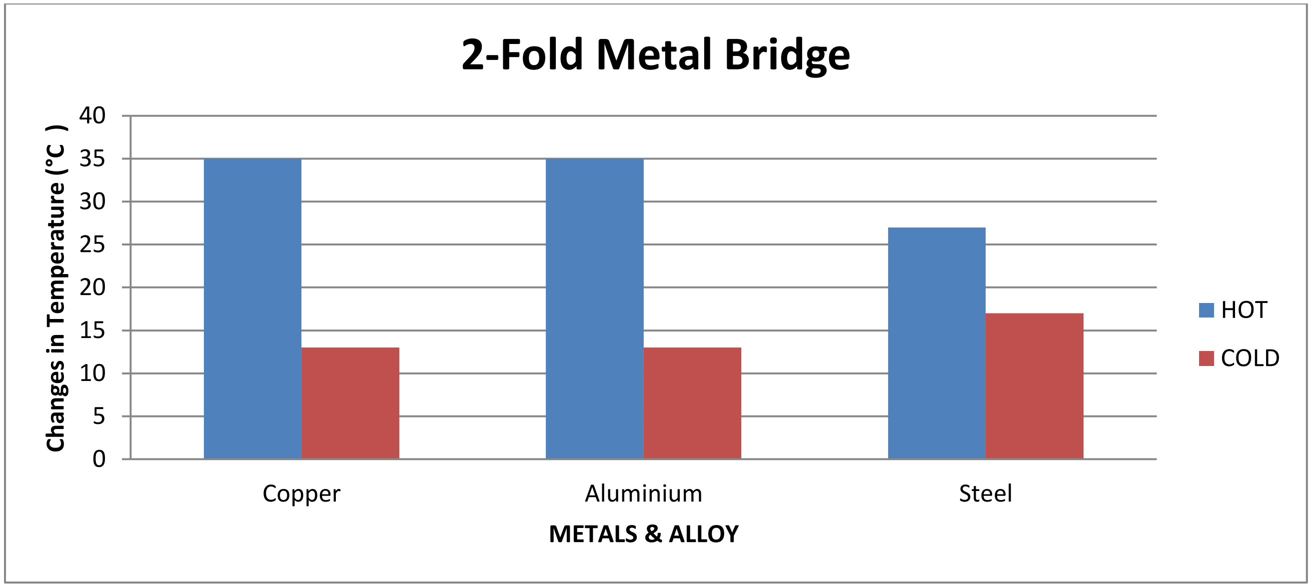
	Initial Temperature (°C)	Final Temperature (°C)	Changes in Temperature (°C)
Control-Hot	70	40	30
1-fold metal bridge-Hot	70	41	29
2-fold metal bridge-Hot	69	42	27
3-fold metal bridge-Hot	69	39	30
Control-Cold	5	18	13
1-fold metal bridge-Cold	5	18	13
2-fold metal bridge-Cold	5	22	17
3-fold metal bridge-Cold	5	18	13

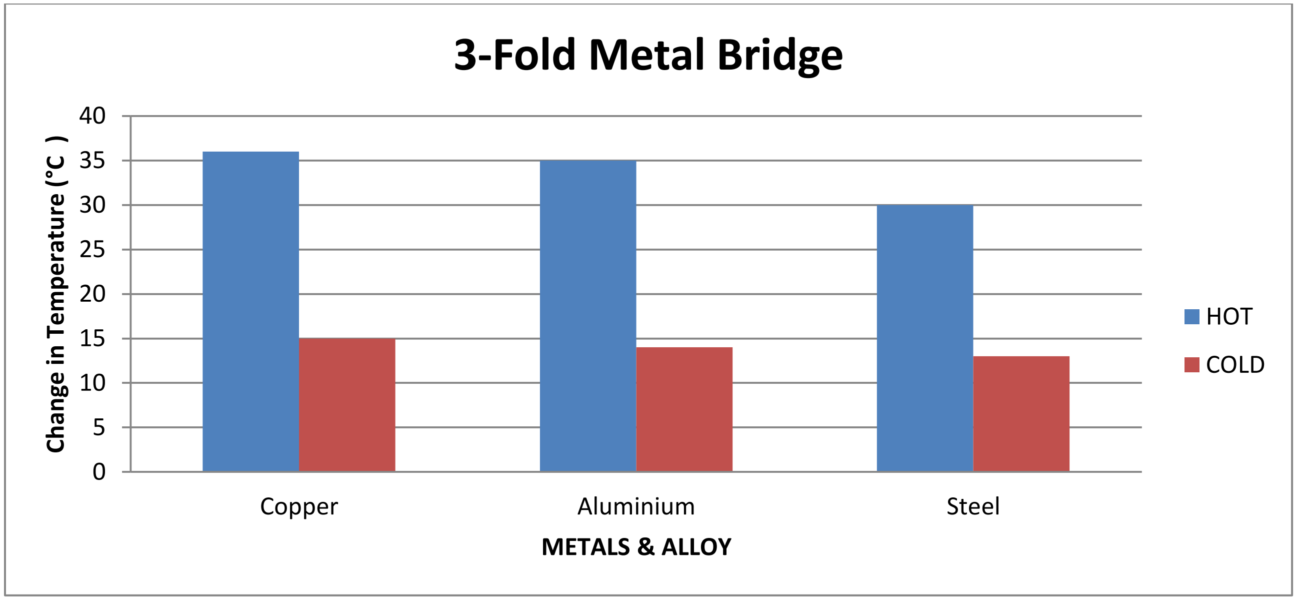
COMPARING THE CHANGES IN TEMPERATURE

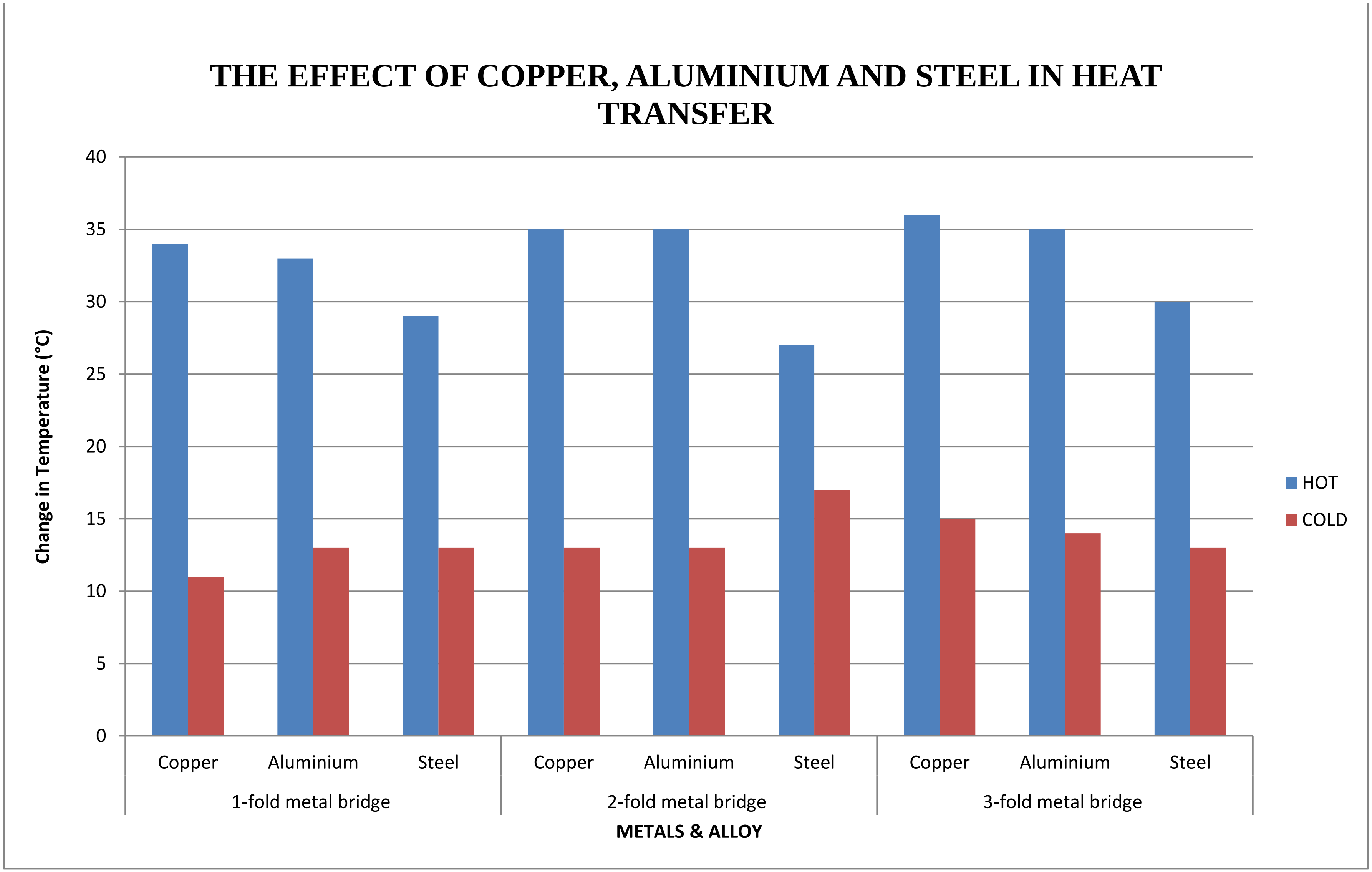
	1-fold metal bridge (°C)			2-fold metal bridge (°C)			3-fold metal bridge (°C)		
	Copper	**Aluminium**	**Steel**	**Copper**	**Aluminium**	**Steel**	**Copper**	**Aluminium**	**Steel**
HOT	34	33	29	35	35	27	36	35	30
COLD	11	13	13	13	13	17	15	14	13

GRAPHS


1-Fold Metal Bridge
40
35
30
25
20
15
10
5
0
CHANGES IN TEMPERATURE (°C)
Copper
Aluminium
Steel
METALS & ALLOY
HOT
COLD

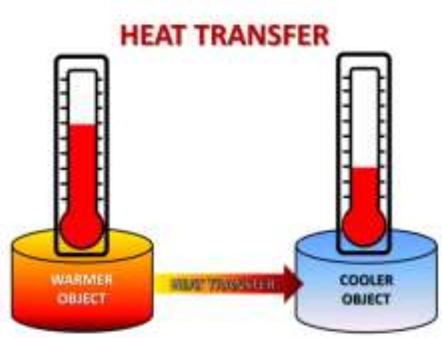

2-Fold Metal Bridge
Changes in Temperature (°C)
40
35
30
25
20
15
10
5
0
Copper
Aluminium
Steel
METALS & ALLOY
HOT
COLD


3-Fold Metal Bridge
Change in Temperature (°C)
40
35
30
25
20
15
10
5
0
Copper
Aluminium
Steel
METALS & ALLOY
HOT
COLD


THE EFFECT OF COPPER, ALUMINIUM AND STEEL IN HEAT TRANSFER
Change in Temperature (°C)
0
5
10
15
20
25
30
35
40
Copper
Aluminium
Steel
1-fold metal bridge
2-fold metal bridge
3-fold metal bridge
METALS & ALLOY
HOT
COLD

RESULTS AND DISCUSSION

- At first while doing the experiment I kept all the metal bridges altogether for testing the thermal conductivity. But I felt hard to measure the temperature of all the cups within 5 minute interval. So I decided to test the thermal conductivity of each metal separately and have control for individual metal. But I am conscious in maintaining the initial temperature of both cold and hot water equal for all the metals. I used same water and same stove and refrigerator to heat the water. After that it is easy for me to note the temperature accurately.
- When heat conducts away from the hot cup, not all of that energy go through the metal bridge and into the cold cup. Heat is often lost to its surroundings, and in this case, some of the heat from the hot water will be lost to the air. Similarly, the air in the room will lose some of its heat to the cup of cold water. I tried to minimize heat loss by using Styrofoam cups, because Styrofoam is known to be a great insulator—a material that's a poor conductor of heat. The room temperature while doing the experiment was 32°C.
- Through my investigation I found Copper has the highest heat conductivity value, followed by aluminum while steel has the lowest heat conductivity value.
- I found that as the fold increases the rate of change in temperature also increases in all the metal bridges. Conduction happens best when more molecules are in contact with each other. Folding the metal bridges in half twice allows the heat from the hot cup to travel through more molecules, allowing more heat to travel from the hot cup to the cold cup. Folding the metal bridge only once will still create a good heat bridge, but we would see a smaller temperature change in the cold cups, making it harder to see which metal is the best conductor.



APPLICATION

Thermal Conductivity is the transfer of heat between two object when are physically connected two each other. Whenever two objects of different temperatures come in contact with each other, heat must be transferred between them.

Examples:

- When a person walks barefooted on hot sand in a sunny day, his feat become hot. It’s because heat is transferred from sand to his feet.
- Mercury used in the thermometer to detect body temperature works on the principle of heat conduction.
- When the stove is turned on, it makes the pan hot for cooking food. In this process, phenomenon of heat conduction is used.
- A ice cube is melted in your hand because the heat from your hand transfer to the ice resulting in its melting
- Pouring of hot tea in a cup will make the cup of the also warm because of the heat transfer from tea to the cup.
- Transfer of heat from iron to shirt while pressing is also a good example.
- Transfer of heat during cooking to the food.

CONCLUSION

- My hypothesis, "*Copper is the best thermal conductivity metal when compared with aluminium and steel"* has been proven true.
- Copper is such a great conductor, we use it for things like heating rods and wires. Because steel is a poor conductor and can withstand high temperatures, we use it to build engines in airplanes.
- Aluminum is lightweight, conducts heat well and is fairly inexpensive, making it a popular choice for cooking. During cooking, aluminum dissolves most easily from worn or pitted pots and pans. The longer food is cooked or stored in aluminum, the greater the amount that gets into food. Leafy vegetables and acidic foods, such as tomatoes and citrus products, absorb the most aluminum.
- Steel is an alloy of iron and carbon, and sometimes other elements. Because of its high tensile strength and low cost, it is a major component used in buildings, infrastructure, tools, ships, automobiles, machines, appliances, and weapons. Iron is the base metal of steel.

FUTURE ENHANCEMENT

- Heat conductivity is a very important property when deciding which metal to use for a specific application and the application of metals is wide. I want to continue my experiment through testing the thermal conductivity of different metals and alloys and thereby study the properties and its application in various field for different purposes in detail.

ACKNOWLEDGEMENT

I have taken efforts in this project. However, it would not have been possible without the kind support and help of many individuals. I would like to extend my sincere thanks to all of them.

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