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# Thermal expansion in solids

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# 1 ABSTRACT

This report presents the results of an experiment conducted to determine the coefficient of thermal expansion of three different materials: aluminium, copper, and steel. The initial length of each tube made of the respective material was measured, as well as the length when exposed to hot steam, and the temperature at both conditions. Using the collected data and equation (3), the coefficient of thermal expansion was calculated for each material. The uncertainties were also calculated to determine the accuracy of the results. The experiment found that aluminium had the highest coefficient of thermal expansion, followed by copper and then steel.

# 2 INTRODUCTION

## 2.1 Background

One of the main problems associated with thermal expansion is that it can cause structural damage or failure in materials and structures that are not designed to account for it. For example, bridges, buildings, and pipelines can experience significant stress and deformation due to thermal expansion, especially if they are made of materials with high CTEs or if they are exposed to extreme temperature changes. (Hewitt, Paul, 2001)

Research related to thermal expansion has focused on developing new materials with low CTEs or materials that can actively respond to temperature changes to mitigate the effects of thermal expansion. For example, researchers have developed composites that can change shape in response to temperature changes, allowing them to adapt to thermal expansion without breaking (Qiao Tan, 2014). Another area of research has been the development of alloys with negative CTEs (Mohamed Abedel-Hady Gepreel, 2012), which can contract when heated and expand when cooled, offering potential applications in precision engineering and microelectronics.

## 2.2 Purpose

In this lab report, we will investigate the phenomenon of thermal expansion and measure the CTE of various materials using different methods. We will also explore the factors that can affect CTE measurements and analyze the results to gain a better understanding of the materials' behavior under different temperature conditions. The purpose of this work is to deepen our knowledge of thermal expansion and CTE measurements, and to provide insights that can be useful in various industries.

### 2.3 Content of the work

The report includes detailed information about the initial length of the tubes made of each material, the length measured when the tubes were exposed to hot steam, the temperature of the tubes at both conditions, and the resulting coefficient of thermal expansion calculated using Eq. (3).

# 3 Theory

## 3.1 Theory and principle related to the work

Thermal expansion is the tendency of matter to change in volume in response to temperature alterations. When a substance is heated, its particles move more and thus maintain a greater average separation. Since thermosets are used in solid form they undergo linear thermal expansion. The degree of expansion divided by the change in temperature gives the material's linear coefficient of thermal expansion (α), which is expressed in 1mm− 1 °C− 1 (Mark J. Parker, 2000)

| Metal | Thermal Expansion *($10^{-6}$ in/(in °C))* |
|---|---|
| Aluminum | 23.6 |
| Copper | 17.6 |
| Stainless Steel - S30100 | 9.4<br>16.9 |
| Stainless Steel - S30200, S30300, S30323 | 9.6<br>17.3 |
| Stainless Steel - S30215 | 9.0<br>16.2 |
| Stainless Steel - S30400, S30500 | 9.6<br>17.3 |
| Stainless Steel - S30430 | 9.6<br>17.3 |
| Stainless Steel - S30800 | 9.6<br>17.3 |

| Metal | Thermal Expansion *($10^{-6}$ in/(in °C))* |
|---|---|
| Stainless Steel - S30900, S30908 | 8.3<br>14.9 |
| Stainless Steel - S31000, S31008 | 8.8<br>15.8 |
| Stainless Steel - S31600, S31700 | 8.8<br>15.8 |
| Stainless Steel - S31703 | 9.2<br>16.6 |
| Stainless Steel - S32100 | 9.2<br>16.6 |
| Stainless Steel - S34700 | 9.2<br>16.6 |
| Stainless Steel - S34800 | 9.3<br>16.7 |
| Stainless Steel - S38400 | 9.6<br>17.3 |
| Stainless Steel - S40300, S41000, S41600, 41623 | 5.5<br>9.9 |
| Stainless Steel - S40500 | 6.0<br>10.8 |
| Stainless Steel - S41400 | 5.8<br>10.4 |
| Stainless Steel - S42000, S42020 | 5.7<br>10.3 |
| Stainless Steel - S42200 | 6.2<br>11.2 |
| Stainless Steel - S42900 | 5.7<br>10.3 |

| Metal | Thermal Expansion ***(10$^{-6}$ in/(in $^{o}$C))*** |
|---|---|
| Stainless Steel - S43000, S43020, S43023 | 5.8 10.4 |
| Stainless Steel - S43600 | 5.2 9.36 |
| Stainless Steel - S44002, S44004 | 5.7 10.3 |
| Stainless Steel - S44003 | 5.6 10.1 |
| Stainless Steel - S44600 | 5.8 10.4 |

basic assumptions and approximations of the theory

result that is tested by measurement (Metals - Temperature Expansion Coefficients, n.d.)

### 3.2 Equation

Length of an object depends on temperature following the equation

$L = L_o (1 + \alpha(t - t_o))$ (1)

where L and $L_o$ are lengths at temperatures t and $t_o$, respectively, and α is coefficient of thermal expansion coefficient. Equation (1) can be written by means of length difference $L - L_o = \Delta L$ and temperature difference $t - t_o = \Delta t$ as follows:

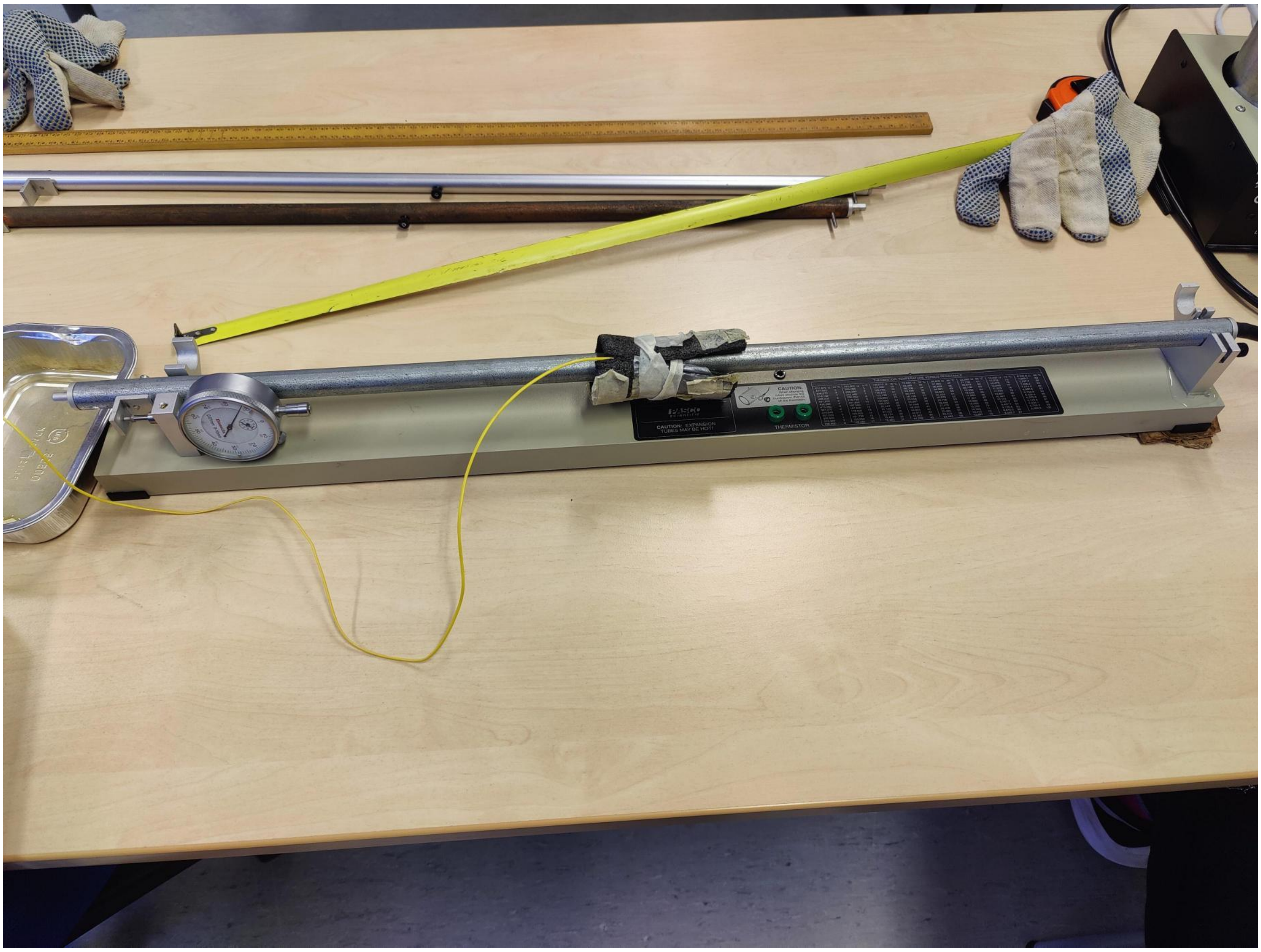
$\Delta L = \alpha L_o \Delta t$ (2)

Coefficient of thermal expansion α can be solved from Eq. (2) as follows

$\alpha = \Delta L / (L_o \Delta t)$ (3)

# 4 Equipment and measurements

## 4.1 Measuring equipment



*Base and micrometer*


*thermocouple thermometer*


*Hot steam*

## 4.2 Measurements

To investigate the thermal expansion of different materials, three tubes made of aluminium, copper, and steel were used. The initial length of each tube was measured using a physical dial gauge with a precision of 0.001 mm. The tubes were then exposed to hot steam, and the resulting length was measured using the same micrometre. The temperature of the tubes was measured using a thermocouple thermometer with a resolution of 0.1 °C. The temperature difference between the cold and hot measurements was used to calculate the CTE of each material using Eq. (3)

## 5 Result

The result of the measurements are recorded in a table like below.

| | Status | Temperature (°C) | Length(mm) | Coefficient of thermal expansion (per °C) |
|---|---|---|---|---|
| Aluminium | Initial<br>Hot<br>(Change) | 23<br>97<br>74 | 743<br>744,24<br>1,24 | 0,000023 |
| Copper | Initial<br>Hot<br>(Change) | 24<br>98<br>74 | 746<br>746,9<br>0,9 | 0,000016 |
| Steel | Initial<br>Hot<br>(Change) | 25<br>96<br>71 | 743<br>743,64<br>0,64 | 0,000012 |

According to the measuring results, we have also calculated the coefficient of thermal expansion (per °C) of aluminium, copper and steel, which is 23 x $10^{-6}$, 16 x $10^{-6}$ and 12 x $10^{-6}$ respectively.

# 6 Conclusions (Reflection)

The literature value of the coefficients of thermal expansion of aluminium, copper and steel are 24 x $10^{-6}$, 17 x $10^{-6}$ and 13 x $10^{-6}$ respectively at 20°C.

Our experiment results are quite similar to the literature values. There are some small differences in the results, as our room temperature is different and there might have been some human errors during the measurement.

# 7 References (Literature references / Sources)

Hewitt, Paul. Conceptual Physics. Englewood Cliffs, NJ: Prentice Hall, 2001.

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