Middle East Technical University

Department of Metallurgical and Material Engineering

Mete206 – Materials Processing Laboratory

Experiment 5: Temperature Measurement

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ABSTRACT

There are a variety of methods to measure temperature which is a critical aspect of any engineering discipline. In this experiment, type-K thermocouple was used to record the temperature behavior of a cooling tin element from above its melting temperature. From the gotten data it was observed that there was not any undercooling and the melting temperature of tin was determined to be 227 ^{0}C. It was calculated that this value had an error of -2.11%. The cooling rates of tin for the liquid phase was found as 0.015 ^{0}C per second and for the solid phase it was found as 0.001 ^{0}C per second.

INTRODUCTION

Material engineering and temperature are two things that are interwind with each other. It is known that the scope of material engineering is in the shape of a triangle with Processing, structure properties and performance all interacting with each other as it can be seen from figure 1.

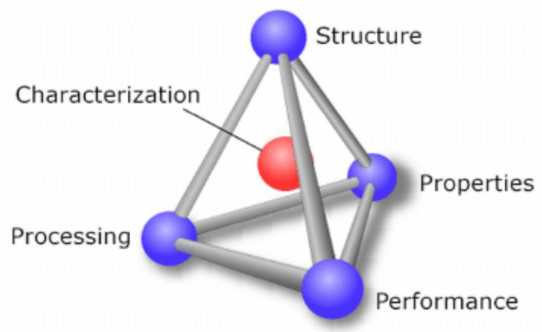

Figure 1. scope of materials engineering (Burkes, 2008)

In all of these temperature plays a vital role. For example, in processing the temperature at which you do a certain process will result in an appropriate change in the microstructure which in result would change the properties of the material. This is a very significant concept as temperature is something that could be manipulated in various ways therefore by manipulating the temperature it is possible to obtain materials that has specific properties that fits the design of an engineer. This is the reason that it is not wrong to say material engineering or in fact engineering in general is not something that can be separated from the importance of temperature.

When the temperature is this important for the engineers there arises the need to measure the temperature in a dependable fast way. Temperature is not something that can be measured directly but rather the changes with the change in temperature is used to make devices to measure temperature like the volumetric expansion, resistance or such physical phenomena will be affected by temperature (R.N. & Phil, 2001).

Temperature measurement, according to the method that it is done can be categorized into two. First one is direct measurement where the sample that the temperature of wants to be known is measured by a device that needs to be in direct contact for it to work. Thermometers that is used daily and based on the volumetric expansion property, bimetallic strips, thermocouples, resistance temperature detectors are some of them that fits the criteria for direct measurement (R.N. & Phil, 2001). The second category for temperature measurement is indirect measurement where the measurement device does not need to be in direct contact with the sample. Infrared thermometry, refractive index methods, spectroscopy, laser induced fluorescence (R.N. & Phil, 2001) can be given as examples to this type of measurement.

In general, it can be said that radiation laws are the theoretical basis for the optical determination of temperature and it can be said that for solid and liquids the methods of total radiance, spectral radiance are the main ways to determine the temperature of the surface based on blackbody radiation (Hornbeck, 1966). Optical methods of temperature measurement are a indirect way of measuring the temperature therefore it comes with significant advantages. It can be said that since it does not need to come in direct contact of the sample that is wanted to be tested, it also does not need to have the durability to endure high temperatures. This allows for saving some cost for the measurement as high temperature resistant materials can be relatively expensive which the direct measuring devices needs to made out of. However, there can also arise the situation where the uncertainty is high for this type of measurement.

In the experiment that has been done, thermocouple is used to record the temperature of a tin element that has been left to cool. It is a direct method of measurement and it allows one to see the use of thermocouples.

One reason that a thermocouple is preferred for many applications is that it has a wide range of temperature that it can work on.

Thermocouple Types			
Type	Conductor Combination	Temperature Range	
		°F	°C
B	Platinum 30% Rhodium / Platinum 6% Rhodium	2500 to 3100	1370 to 1700
E	Nickel-chromium / Constantan	32 to 1600	0 to 870
J	Iron / Constantan	32 to 1400	0 to 760
K	Nickel-chromium / Nickel-aluminium	32 to 2300	0 to 1260
N	Nicrosil / Nisil	32 to 2300	0 to 1260
R	Platinum 13% Rhodium / Platinum	1600 to 2640	870 to 1450
S	Platinum 10% Rhodium / Platinum	1800 to 2640	980 to 1450
T	Copper / Constantan	-75 to +700	-59 to +370

Figure 2. Types of thermocouples (ControlandInstrumentation, n.d)

From figure 2, the types of thermocouples as well as range that they work in can be seen. Another reason for the thermocouples to be preferred is that they are relatively cheap and can be used in variety of manners.

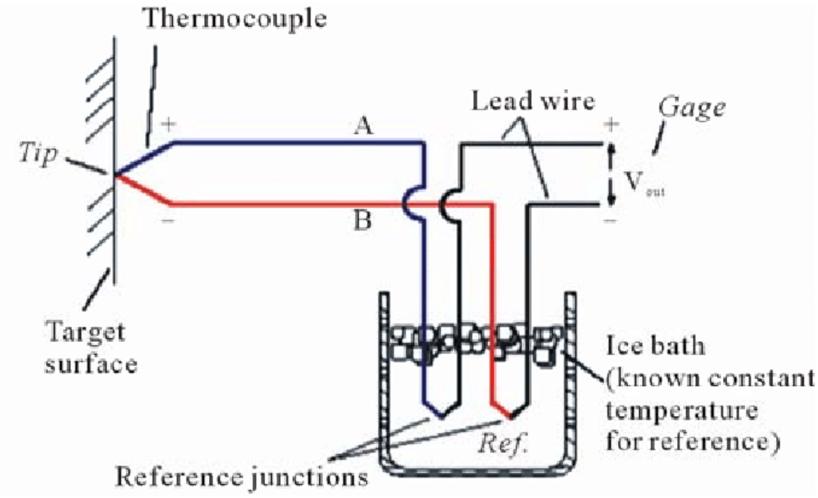

Figure 3. A schematic of a thermocouple (Abdelhady, 2011)

Thermocouple has two different wires connected to each end of a potential measuring instrument that gives the result of the emf created (R.N. & Phil, 2001) which can be looked up from a temperature millivolt table that will give a corresponding temperature for a certain potential difference as the emf is dependent on the temperature. The theory behind comes from the findings of Johann Seeback where he found that a with the difference in temperature of two junctions a small current was created and the resulting emf was related with the magnitude of the temperature (R.N. & Phil, 2001). This is the reason as two different materials are used.

It is mentioned that the use of thermocouples was seen in the course of the experiment. It is also correct to say that in addition to this, it was also aimed to find the cooling curve of tin sample and how it behaved.

EXPERIMENTAL

Material

- Tin sample

Equipment

- K-type thermocouple
- Vertical tube furnace
- Potentiometer
- Extended wires
- Glass tube
- Calibration cell

Procedure

The furnace was allowed to heat 1 hour before the experiment. After the pre-determined temperature was reached inside the furnace, it was shut down and was allowed to cool. At this point in time, the time was recorded and the potential difference values were noted for 30 seconds for 25 minutes. To obtain the corrected potential difference values 1.08 mV was added to the data and the corresponding temperatures were gotten from the table that can be found in the appendix.

RESULT

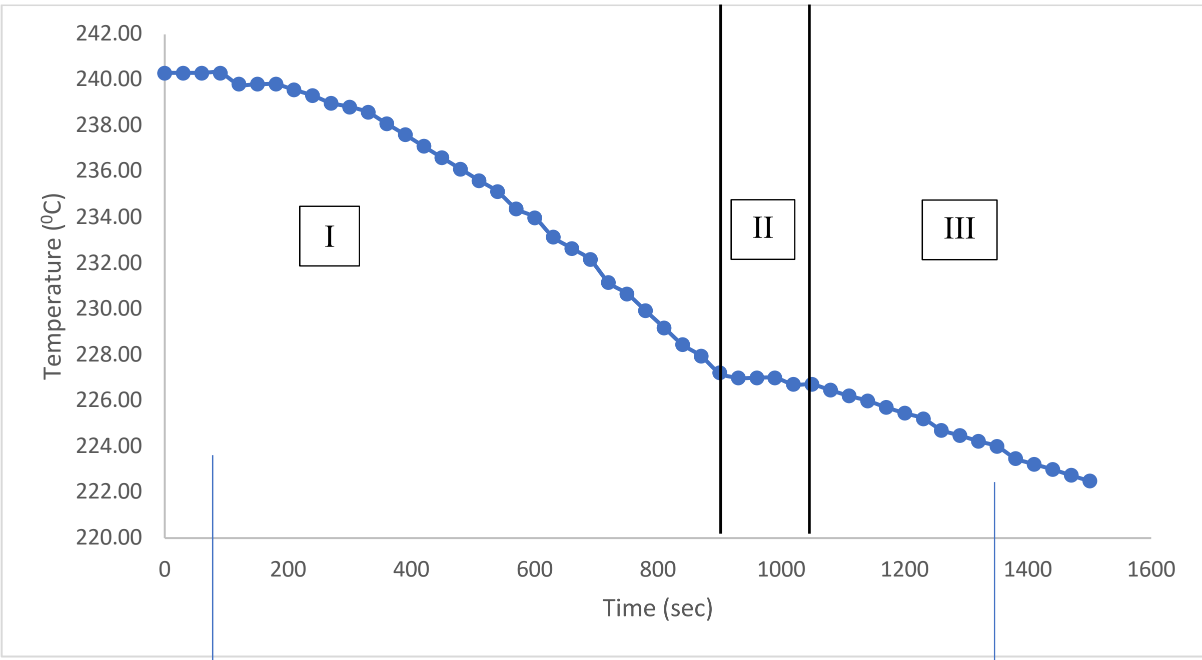

Figure 4. The cooling graph of tin segmented into three parts

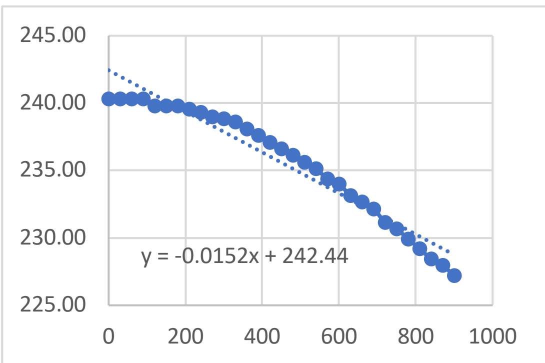

Figure 5. The cooling graph of liquid tin up to melting temperature

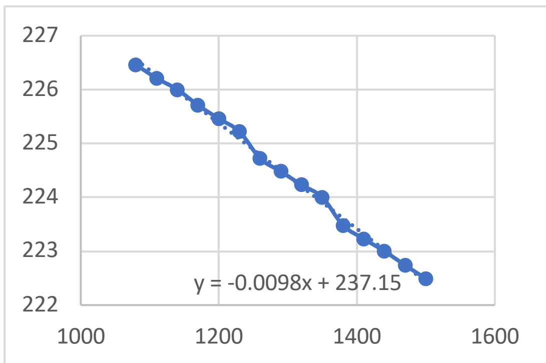

Figure 6. The cooling graph of solid tin

In figure 4 the change in temperature with respect to time can be seen for the tin metal. It is segmented to three parts where in the first part the tin is in liquid state, in the second part it is changing from liquid to solid and finally in the third part it is in solid state.

When it is looked at figure 4 generally, it can be seen that there is a general decrease of temperature up to the 900th second where it remains constant for some time and starts to decrease again afterwards.

Figure 5 and figure 6 are the graphs of only segment I and segment III respectively.

DISCUSSION

The procedure to obtain the data for figure 4 has been mentioned above. However, it is important to note that the obtained data is not something that can be directly used to make the plot. First, some correction needs to be done. The reason for the correction is that the cold junction was at room temperature which is 27 ^{0}C and the type k temperature vs millivolt table which can be found in the appendix takes the cold junction temperature to be 0 ^{0}C. To overcome this, a correction needs to be done on the obtained potential difference values. From the table, the value of millivolt at temperature of 27 ^{0}C is found and noted which is 1.08 mV. This value is then added to the potential difference values that was found in the duration of the experiment. With the corrected potential difference values and the help of the table the time vs temperature graph that is seen as figure 4 can be plotted.

When figure 4 is examined, it can be seen that there is no undercooling that has occurred. The reason can be correlated to the fact that the tin that was in the forge was not entirely pure. This can be considered as it is very hard to obtain a pure element and even in the case that it is obtained, inside the forge the impurities would likely diffuse into the sample (Hayes, 1911). This can also be the reason for the curve to be not exactly linear up to the 900th second. In addition to this the temperature intervals are recorded every 30 seconds therefore if the undercooling occurred and stabilized within the 30 seconds than that might also result in not being able to observe it in figure 4.

At the 900th second it is seen that the temperature stays constant for a period of time, up to 1050th second where it once again starts to decrease. This is the time interval in which the liquid tin transforms into solid and the temperature at which this transformation takes place is the melting temperature of tin. Therefore, it is not wrong to say that tin has an approximate melting point of 227 ^{0}C.

Figure 5, which is the cooling curve of the liquid tin can provide us with the information of the cooling rate for liquid phase. A linear trendline has been put in both figure 5 and 6 where the equations therefore the slope can be found. The slope gives one the cooling rates. In figure 5 the slope is found as -0.015 where the minus indicates a decrease of temperature and it can be said that for the liquid phase the cooling rate is 0.015 ^{0}C per second. For the solid phase in figure 6, the slope is found as -0.001 which means that it has a cooling rate of 0.001 ^{0}C per second. Therefore, it can be said that the liquid phase cooling rate is higher than solid phase.

The theoretical melting temperature is found as 231.9 ^{0}C. From the experiment it is determined that the melting point as approximately 227 ^{0}C. The percent error can be found as;

$$\%\, error = \frac{227 - 231.9}{231.9} \cdot 100 = -2.11\%$$

The reason can be again correlated with the impurity that may arise inside of pure tin in the duration of experiment or in the synthesis of tin. However, there might be other factors. For example, the difference in pressure where the experiment has been carried out might make a difference as well as the error factor that comes with the usage of an old machine. To add to this, since thermocouple is a under direct measurement category it needs to be in direct contact with the sample, meaning that it is possible for the thermocouple to have distorted the temperature when it came in contact with the sample (R.N. & Phil, 2001).

To prevent the error a furnace that is composed of a thin metal that would diffuse very little and a very pure tin element can be used to do the experiment where environmental factors does very little to change the result of the experiment and make sure that the thermocouple does not alter the temperature significantly.

CONCLUSION

Temperature is a very important aspect of engineering as many applications are dependent on it. This arises the need to measure temperature in an efficient, cheap fast way. There are many methods to do the measurements and, in this experiment, thermocouple was used which is a direct way of measuring temperature. Thermocouples are separated into different types based on the materials that they are made of and in the case of the experiment, type k Chromel-Alumel wire combination was used. It was used to record the temperature of a tin element as it cooled from above its melting temperature. Doing so the melting temperature of tin was able to be determined though with a percent error. The cooling rates of liquid and solid phases was also computed. All in all, by using a common temperature measurement method the cooling graph of tin was able to be obtained.

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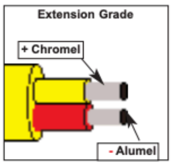
APPENDIX

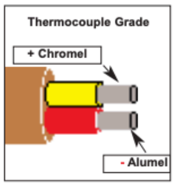
Technical Information Data Bulletin

Type K Thermocouple
Chromel-Alumel

TEMPERATURE & PROCESS INSTRUMENTS INC



Temperature vs Millivolt Table
Reference Junction 0°C



Temperature Range
Maximum Useful Temperature Range:
Thermocouple Grade: -328 to 2282°F
-200 to 1250°C
Extension Grade: 32 to 392°F
0 to 200°C

Maximum Thermocouple Grade
Temperature Range
–454 to 2501°F
–270 to 1372°C
Accuracy: Standard: 2.2°C or 0.75%
Special: 1.1°C or 0.4%

Recommended Applications:
Clean Oxidizing and Inert Environoments, Limited Use in Vacuum or Reducing Environoment

Temp	0	1	2	3	4	5	6	7	8	9
180	7.3400	7.3799	7.4199	7.4598	7.4997	7.5396	7.5795	7.6194	7.6593	7.6992
190	7.7391	7.7790	7.8190	7.8589	7.8988	7.9387	7.9787	8.0186	8.0586	8.0985
200	8.1385	8.1784	8.2184	8.2584	8.2984	8.3384	8.3784	8.4185	8.4585	8.4985
210	8.5386	8.5787	8.6187	8.6588	8.6990	8.7391	8.7792	8.8194	8.8595	8.8997
220	8.9399	8.9801	9.0203	9.0606	9.1008	9.1411	9.1814	9.2217	9.2620	9.3023
230	9.3427	9.3831	9.4234	9.4638	9.5043	9.5447	9.5852	9.6256	9.6661	9.7066
240	9.7472	9.7877	9.8283	9.8688	9.9094	9.9500	9.9907	10.0313	10.0720	10.1127
250	10.1534	10.1941	10.2348	10.2756	10.3163	10.3571	10.3979	10.4388	10.4796	10.5205
260	10.5613	10.6022	10.6431	10.6840	10.7250	10.7659	10.8069	10.8479	10.8889	10.9299
270	10.9709	11.0120	11.0531	11.0941	11.1352	11.1763	11.2175	11.2586	11.2998	11.3409
280	11.3821	11.4233	11.4645	11.5058	11.5470	11.5882	11.6295	11.6708	11.7121	11.7534
290	11.7947	11.8360	11.8774	11.9187	11.9601	12.0015	12.0429	12.0843	12.1257	12.1671
300	12.2086	12.2500	12.2915	12.3330	12.3744	12.4159	12.4574	12.4990	12.5405	12.5820
310	12.6236	12.6651	12.7067	12.7483	12.7899	12.8315	12.8731	12.9147	12.9563	12.9980
320	13.0396	13.0813	13.1230	13.1646	13.2063	13.2480	13.2897	13.3314	13.3731	13.4149
330	13.4566	13.4984	13.5401	13.5819	13.6237	13.6654	13.7072	13.7490	13.7908	13.8327
340	13.8745	13.9163	13.9582	14.0000	14.0419	14.0837	14.1256	14.1675	14.2094	14.2512
350	14.2931	14.3351	14.3770	14.4189	14.4608	14.5028	14.5447	14.5867	14.6286	14.6706
360	14.7126	14.7546	14.7965	14.8385	14.8806	14.9226	14.9646	15.0066	15.0486	15.0907
370	15.1327	15.1748	15.2168	15.2589	15.3010	15.3431	15.3851	15.4272	15.4693	15.5114
380	15.5536	15.5957	15.6378	15.6799	15.7221	15.7642	15.8064	15.8485	15.8907	15.9329
390	15.9750	16.0172	16.0594	16.1016	16.1438	16.1860	16.2282	16.2704	16.3127	16.3549
400	16.3971	16.4394	16.4816	16.5239	16.5662	16.6084	16.6507	16.6930	16.7353	16.7775
410	16.8198	16.8621	16.9044	16.9468	16.9891	17.0314	17.0737	17.1161	17.1584	17.2007
420	17.2431	17.2854	17.3278	17.3702	17.4125	17.4549	17.4973	17.5397	17.5821	17.6245
430	17.6669	17.7093	17.7517	17.7941	17.8365	17.8789	17.9214	17.9638	18.0062	18.0487
440	18.0911	18.1336	18.1760	18.2185	18.2609	18.3034	18.3459	18.3884	18.4308	18.4733
450	18.5158	18.5583	18.6008	18.6433	18.6858	18.7283	18.7708	18.8133	18.8559	18.8984
460	18.9409	18.9834	19.0260	19.0685	19.1110	19.1536	19.1961	19.2387	19.2812	19.3238
470	19.3663	19.4089	19.4515	19.4940	19.5366	19.5792	19.6218	19.6643	19.7069	19.7495
480	19.7921	19.8347	19.8773	19.9199	19.9625	20.0051	20.0477	20.0903	20.1329	20.1755
490	20.2181	20.2607	20.3033	20.3459	20.3885	20.4312	20.4738	20.5164	20.5590	20.6017
500	20.6443	20.6869	20.7295	20.7722	20.8148	20.8574	20.9001	20.9427	20.9854	21.0280
510	21.0706	21.1133	21.1559	21.1986	21.2412	21.2838	21.3265	21.3691	21.4118	21.4544
520	21.4971	21.5397	21.5824	21.6250	21.6677	21.7103	21.7530	21.7956	21.8383	21.8809
530	21.9236	21.9662	22.0089	22.0515	22.0942	22.1368	22.1794	22.2221	22.2647	22.3074
540	22.3500	22.3927	22.4353	22.4780	22.5206	22.5632	22.6059	22.6485	22.6912	22.7338
550	22.7764	22.8191	22.8617	22.9043	22.9470	22.9896	23.0322	23.0748	23.1175	23.1601
560	23.2027	23.2453	23.2879	23.3306	23.3732	23.4158	23.4584	23.5010	23.5436	23.5862
570	23.6288	23.6714	23.7140	23.7566	23.7992	23.8418	23.8843	23.9269	23.9695	24.0121
580	24.0547	24.0972	24.1398	24.1824	24.2249	24.2675	24.3100	24.3526	24.3951	24.4377
590	24.4802	24.5228	24.5653	24.6078	24.6504	24.6929	24.7354	24.7779	24.8204	24.8630
600	24.9055	24.9480	24.9905	25.0330	25.0755	25.1179	25.1604	25.2029	25.2454	25.2878
610	25.3303	25.3728	25.4152	25.4577	25.5001	25.5426	25.5850	25.6275	25.6699	25.7123
620	25.7547	25.7971	25.8395	25.8820	25.9244	25.9668	26.0091	26.0515	26.0939	26.1363
630	26.1786	26.2210	26.2634	26.3057	26.3481	26.3904	26.4328	26.4751	26.5174	26.5597
640	26.6020	26.6444	26.6867	26.7290	26.7712	26.8135	26.8558	26.8981	26.9403	26.9826
650	27.0249	27.0671	27.1094	27.1516	27.1938	27.2360	27.2783	27.3205	27.3627	27.4049

Figure 7. Temperature vs millivolt table of type K thermocouple (TnP instruments, n.d)

Table 1. Raw data of the cooling graph of tin

Time(sec)	Pot.Diff.(mV)	Corrected Pot.Diffi.(mV)	Temperature (°C)
0	8.68	9.76	240.32
30	8.67	9.75	240.32
60	8.67	9.75	240.32
90	8.67	9.75	240.32
120	8.66	9.74	239.82
150	8.66	9.74	239.82
180	8.66	9.74	239.82
210	8.65	9.73	239.58
240	8.64	9.72	239.33
270	8.63	9.71	239.00
300	8.62	9.7	238.84
330	8.61	9.69	238.59
360	8.59	9.67	238.10
390	8.57	9.65	237.62
420	8.55	9.63	237.11
450	8.53	9.61	236.61
480	8.51	9.59	236.12
510	8.49	9.57	235.62
540	8.47	9.55	235.13
570	8.44	9.52	234.39
600	8.42	9.5	234
630	8.39	9.47	233.15
660	8.37	9.45	232.66
690	8.35	9.43	232.16
720	8.31	9.39	231.17
750	8.29	9.37	230.67
780	8.26	9.34	229.93
810	8.23	9.31	229.19
840	8.2	9.28	228.45
870	8.18	9.26	227.95
900	8.15	9.23	227.21
930	8.14	9.22	227
960	8.14	9.22	227
990	8.14	9.22	227
1020	8.13	9.21	226.71
1050	8.13	9.21	226.71
1080	8.12	9.2	226.46
1110	8.11	9.19	226.21
1140	8.1	9.18	226
1170	8.09	9.17	225.71
1200	8.08	9.16	225.46
1230	8.07	9.15	225.22
1260	8.05	9.13	224.72
1290	8.04	9.12	224.48
1320	8.03	9.11	224.23
1350	8.02	9.1	224
1380	8	9.08	223.48
1410	7.99	9.07	223.23
1440	7.98	9.06	223
1470	7.97	9.05	222.74
1500	7.96	9.04	222.49