Middle East Technical University

Department of Metallurgical and Material Engineering

Mete206 – Materials Processing Laboratory

Experiment 2: Property Control by Heat Treatment

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ABSTARCT

The heat treatment of six specimens was done and the hardness values of the specimens were measured by rockwell testing machine. Three different types of steel were used. Namely, AISI 1050, AISI 1020 and AISI H13. AISI 1050 and 1020 steels were left in the furnace at 950 ^oC for 15 minutes and AISI H13 steel was left in the furnace at 1100 ^oC for again 15 minutes. The six specimens were cooled in different ways and the effect of cooling mediums were observed. Apart from the cooling mediums, the effect of composition and alloying element were also examined. It was found that water quenching of AISI 1050 steel resulted in the hardest specimen and the softest was furnace cooled AISI 1020 metal.

INTRODUCTION

An engineer must be able to find solutions to problems. In the case of material engineers, it can be said that they engineer materials. With the help of certain processes, a material is engineered to have the desired properties. One such process to play with the properties of a material is heat treatment. Heat treatment, is the cooling and/or heating of a material in a certain amount of time to achieve the desired properties (Singh, 2016).

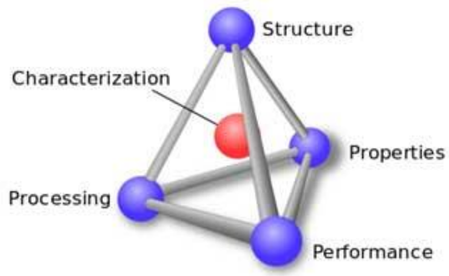

Figure 1. The triangular prism for material engineering (Electrical4U, 2020)

Figure 1 illustrates, processing controls microstructure and the microstructure determines the properties of the material which leads to the performance. Therefore, one can see the importance of the process that is done on the material as it directly corelates with the final properties as well as the performance of the said material. For example, if one wants the metal to be hard than the process would be performed in such a way that in the microstructure, martensite is observed or if one wants a soft metal than austenite should be seen in the microstructure. What gives the engineer an idea of the microstructure at certain compositions and temperature are phase diagrams. There is more than one type of phase diagrams. The fastness of the cooling is a major influence for the determination of the type of phase diagram that will be used.

In the case of slow cooling where there is time for diffusion to occur and the phases are stable meaning that they are in a state of minimum energy and maximum disorder, equilibrium phase diagrams are used. However, if the cooling is done relatively faster than the phases starts to become metastable and there will not be that much time for diffusion. TTT diagrams are used in such scenarios.

For the equilibrium phase diagram of an iron carbon alloy, ferrite, austenite, cementite phases exist stably at certain temperature and composition ranges (William D. Callister JR., 2016).
Ferrite is a soft material while cementite is a hard material therefore the engineers can arrange the amounts of them to make a hard, soft or something in between allow with help of this phase diagram. They can do it by cooling the material from a certain temperature and allowing the austenite phase undergoing a eutectoid reaction forming a structure named as pearlite. This

pearlite has the mechanical property as something in between of hard and soft (William D. Callister JR., 2016). The amount of pearlite can be again controlled by choosing the composition of carbon which will affect the amount of austenite that will undergo the eutectoid reaction.

Equilibrium phase diagram is straightforward and allows the understanding of the microstructure at certain temperatures and compositions. However, it is not enough as the time that is needed to be waited for an equilibrium cooling can be said to be equal to loss of money. Therefore, fast cooling is something that is often seen. When fast cooling is done the cooling is non-equilibrium and TTT diagrams are used. From the diagram if one knows the cooling rate than just like in equilibrium cooling one can determine the resulting microstructure. Meaning that the rate of cooling is a critical parameter that affects the microstructure which as discussed affects the properties of the material. To regulate the rate of cooling there are certain mediums that are being used. Namely, water, oil, air and furnace cooling where water cooling is the fastest and furnace cooling is the slowest way of cooling.

Furnace cooling is the act of leaving the material in the furnace to cool on its own. As one can expect this takes a lot of time but this type of cooling is considered as equilibrium cooling. Air cooling is the act of taking the material and leaving it to cool outside of the furnace, oil cooling is the act of putting the material inside the oil for it to cool and if put on water than it is named as water cooling.

It is important to note that the alloying element also has certain effects on the TTT diagram. The effect can be said to be the shifting of the curve in the TTT diagram.

EXPERIMENTAL

Materials

- AISI 1050 steel
- AISI 1020 steel
- AISI H13 alloy steel

Equipment

- Tongs
- Furnace
- Water
- Oil
- Rockwell Hardness tester
- Grinding Machine

Procedure

Two furnaces are set to temperatures 950 ^{o}C and 1100 ^{o}C and are allowed to pre-heat. The AISI 1050 and AISI 1020 steels are put into the furnace that is at 950 ^{o}C and the AISI H13 is put into the 1100 ^{o}C furnace. After a period of 15 minutes one of the AISI 1050 steel is left to cool inside the furnace for 24 hours, another one is taken with the help of a tong and is cooled by putting it inside a water tank which takes about 15 seconds to cool, similarly another one is also taken by a tong but is dropped in oil allowing it to cool in about 15 minutes and the final one is taken out of the furnace and is left out in the open for it to cool by air. It cools in about 35 minutes. In total four AISI 1050 specimen are cooled in different methods. The AISI 1020 steel that was also inside the 950 ^{o}C furnace is also cooled by furnace cooling method. H13 steel that was inside a 1100 ^{o}C furnace for 15 minutes is left to cool by air for 35 minutes. All the specimen after they were cooled underwent a grinding process as to eliminate the oxide layer and to make a flat surface which will allow the following hardness testing. To test the hardness rockwell hardness testing machine was used. Two types were used; B and C. B does 100kgf of force and is used when measuring the hardness of soft materials which in this case was the ones that were exposed to furnace cooling. C does 150 kgf amount of force and it is used on harder materials which was the ones that went other types of cooling processes than furnace cooling. The material of the tip also changes. B has a tip material of hardened steel and C has the tip material, diamond. Once every sample was measured for their hardness in more than one point to get an accurate result, the results were tabulated and all the hardness values were changed to HV.

RESULT

Type of Metal	Type of Cooling	Cooling time	Hardness Test #1	Hardness Test #2	Hardness Test #3	Hardness Test #4	Hardness Test #5	Average Hardness	Standard Deviation
1020	Furnace cooling	24 hours	80 HRB	67 HRB	65 HRB	66 HRB	70 HRB	69.6 HRB	5.4626
1050	Furnace cooling	24 hours	87 HRB	84 HRB	85 HRB	86 HRB	83 HRB	85.0 HRB	1.4142
1050	Water cooling	15 seconds	54 HRC	68 HRC	68 HRC	63 HRC	68 HRC	64.2 HRC	5.4553
1050	Oil cooling	15 minutes	45 HRC	41 HRC	42 HRC	42 HRC	49 HRC	43.8 HRC	2.9257
1050	Air Cooling	35 minutes	18 HRC	19 HRC	21 HRC	17 HRC	18 HRC	18.6 HRC	1.3565
H13	Air cooling	35 minutes	52 HRC	51 HRC	54 HRC	54 HRC	53 HRC	52.8 HRC	1.1662

Table 1. The tabulated results of the hardness values in HRB and HRC unit

In table 1 the tabulated results for the hardness testing can be seen.

Table 2. The tabulated results of the hardness values in HV unit

Type of Metal	Type of Cooling	Cooling time	Hardness Test #1	Hardness Test #2	Hardness Test #3	Hardness Test #4	Hardness Test #5	Average Hardness	Standard Deviation
1020	Furnace cooling	24 hours	150 HV	119 HV	116 HV	117 HV	125 HV	125.4 HV	12.6902
1050	Furnace cooling	24 hours	172 HV	162 HV	165 HV	169 HV	159 HV	165.4 HV	4.6733
1050	Water cooling	15 seconds	577 HV	940 HV	940 HV	772 HV	940 HV	833.8 HV	143.9450
1050	Oil cooling	15 minutes	446 HV	402 HV	412 HV	412 HV	418 HV	418 HV	14.9131
1050	Air Cooling	35 minutes	232 HV	235 HV	243 HV	229 HV	232 HV	234.2 HV	4.7917
H13	Air cooling	35 minutes	544 HV	528 HV	577 HV	577 HV	560 HV	557.2 HV	19.0725

Due to reasons that will be explained in the discussion part of the report there were a need for the results that were seen in table 1 to be turned into that of HV unit. Table 2 shows the results of hardness testing in terms of HV units.

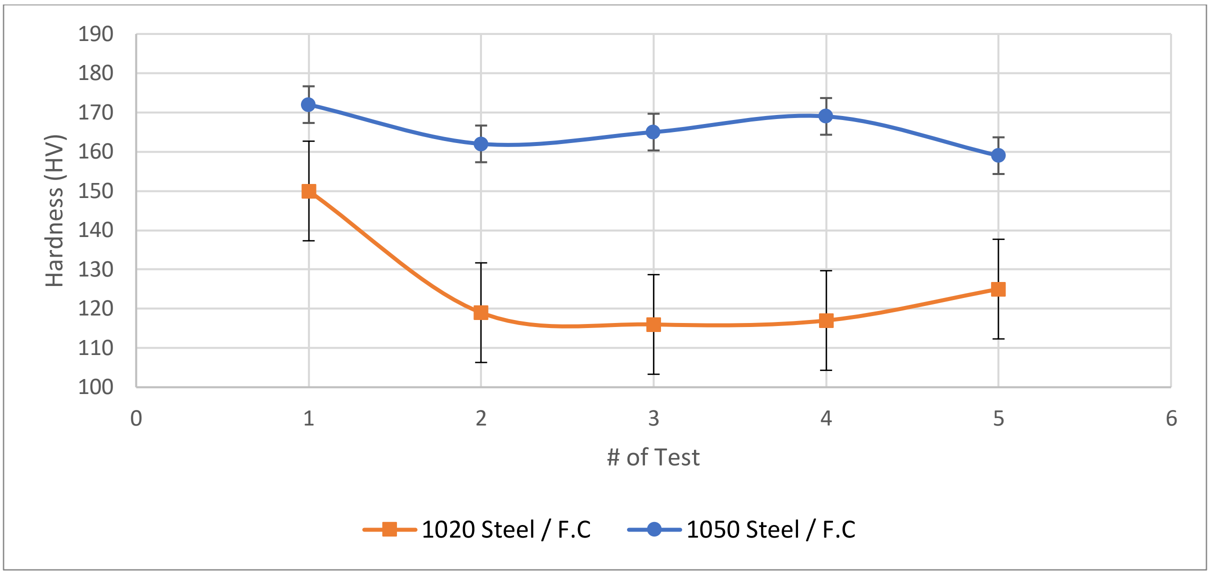

Figure 2. The comparison of alloys with different carbon content

Figure 2 illustrates the difference of hardness between two similar steels but with different carbon content. It can be seen that AISI 1050 steel that was cooled by furnace cooling is the harder one with the hardness of approximately 165 HV while AISI 1020 steel has a hardness of about 130 HV

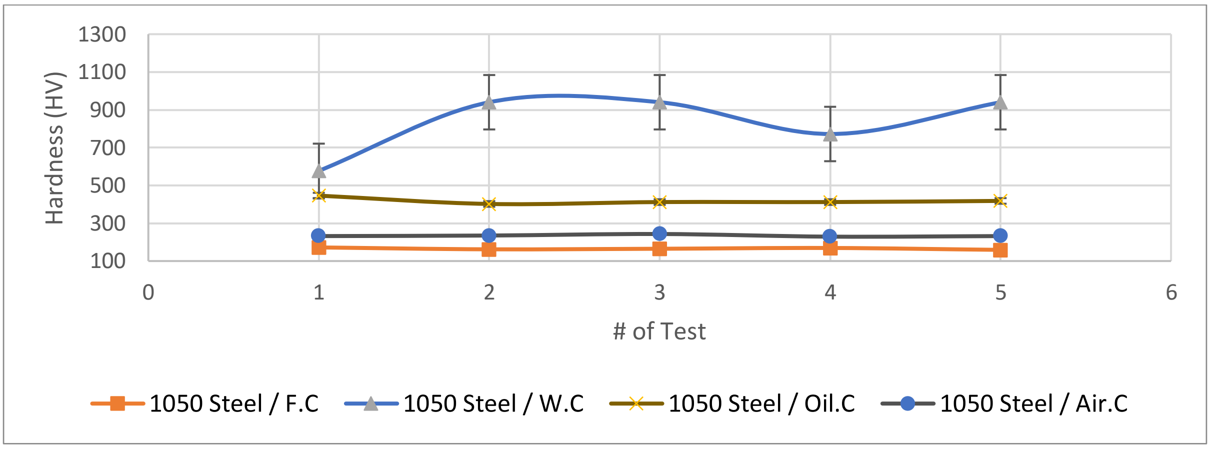

Figure 3. The effect of different cooling mediums on hardness for the same alloy

Figure 3 compares the effect on different types of cooling processes on hardness. From the graph It will be correct to say that water cooling makes the steel the hardest followed by oil cooling, air cooling and finally furnace cooling. Therefore, this can be interpreted as with the decrease in cooling time the hardness increases for AISI 1050 steel.

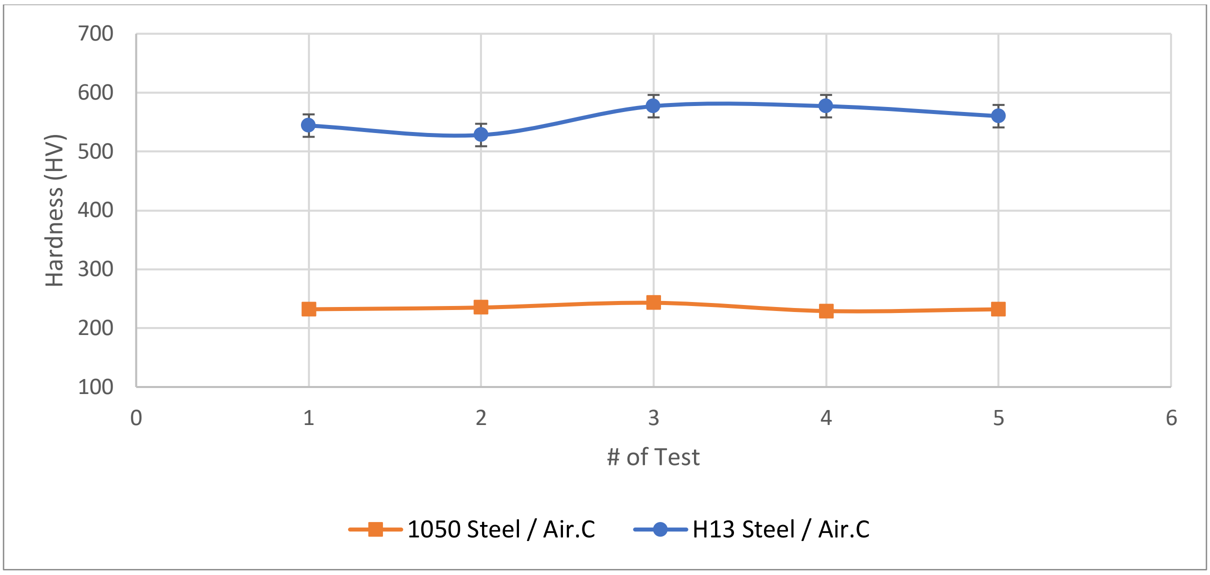

Figure 4. The effect of alloying content on the hardness property

By looking at Figure 3 it can clearly be seen that AISI H13 steel which is a high steel alloy is harder than AISI 1050 Steel when both of them are air cooled. From this one can conclude that by alloying the hardness of the steel increases.

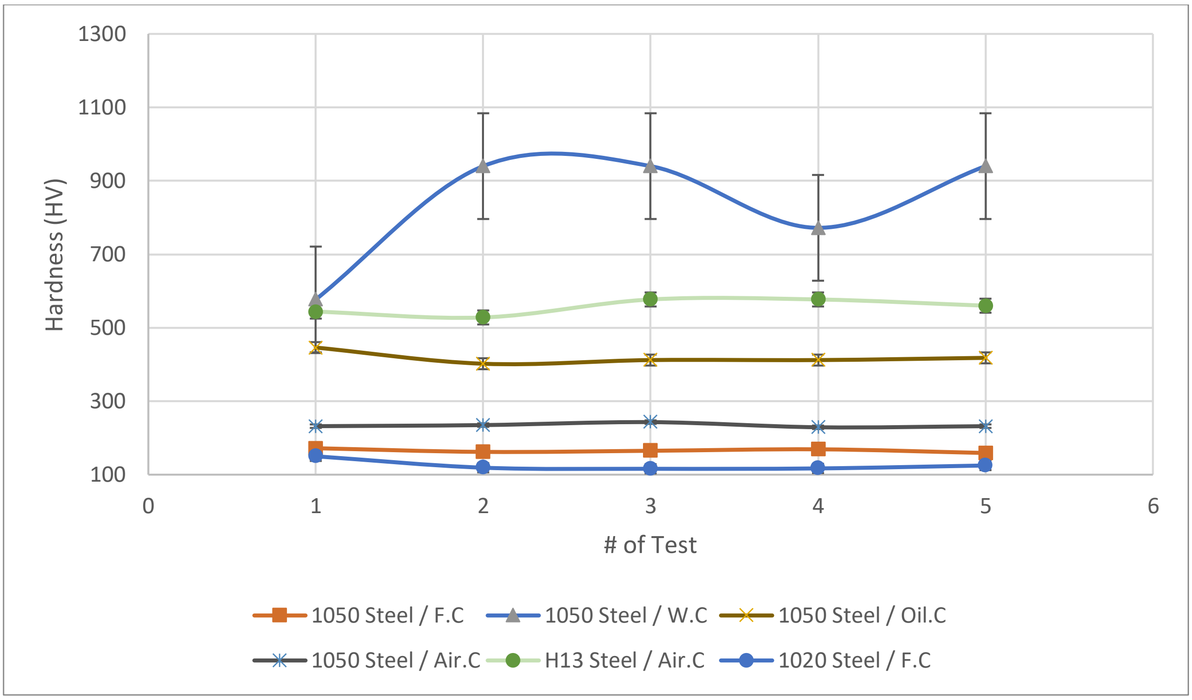

Figure 5. All the testing results from the experiment in one graph

By analyzing figure 5, the hardest specimen was obtained by water cooling the AISI 1050 steel. And the softest was the AISI 1020 steel that was air cooled. To rank all of them from hardest to softest;

1050/W.C > H13/A.C > 1050/O.C > 1050/A.C > 1050/F.C > 1020/F.C

DISCUSSION

In this experiment 6 different specimens were used. Some of them had different cooling processes done on them and others had different carbon content or alloying.

It is important to note that AISI 1020 and 1050 steel was left for 15 minutes at 950 ^{o}C degrees furnace where else the AISI H13 steel was left for again 15 minutes but at the temperature of 1100 ^{o}C inside the furnace. In both cases the aim is to obtain full austenite structure. In H13 steel due to alloying the curve shifts therefore to make up for the shift the process on obtaining austenite structure is changed such that H13 steel is put on 1100 ^{o}C furnace.

At 950 ^{o}C, as aimed the AISI 1020 and 1050 steels had the phase of austenite.

Also, the reason as to why more than one hardness value is obtained with one specimen is that to get more accurate results more measurements must be done. In table 1 and 2 the value of each measurement is recorded. The average and standard deviation is also calculated. The standard deviation on table 2 that is found is used on determining the error bars which can be seen at every graph.

The standard error was calculated by the equation;

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(X_i - \mu)^2}$$

To give one example for the values of table 2 AISI 1020 furnace cooled steel;

$$\sigma = \sqrt{\frac{(150 - 124.4)^2 + (119 - 124.4)^2 + (116 - 124.4)^2 + (117 - 124.4)^2 + (125 - 124.4)^2}{5}}$$

Which equals 12.062.

Table 2 is very similar to table 1. The only difference is that the unit for the values at table 2 is HV. This must be done as in this experimented all the specimens are needed to be compared and to compare them with each other they need to comparable meaning that they need to be of the same unit.

In figure 2, it was concluded that AISI 1050 steel was harder than 1020 steel when both of them were furnace cooled. Furnace cooled means that equilibrium cooling took place and equilibrium phase diagram can be used. With the help of the phase diagram it is seen that for AISI 1050 steel the amount of austenite phase is higher in amount. This means that with the eutectoid reaction the amount of pearlite formed for AISI 1050 steel is much more. As a result the 1050 steel is more harder.

In figure 3, four different AISI 1050 metals which are cooled in different mediums and their hardness values can be seen. The conclusion that with faster cooling rate the harder the steel becomes was done. This again is due to the change in microstructure however since it is non equilibrium cooling TTT diagrams must be used to understand the change in microstructure.

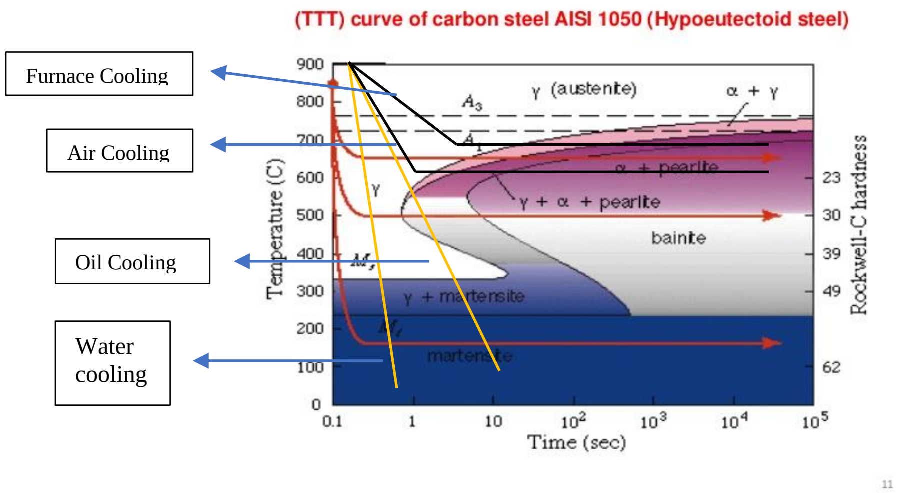

Figure 6. TTT curve of AISI 1050 steel (Siddiqui, 2015)

Figure 6 is the TTT diagram of AISI 1050 steel. The effects of the cooling medium types can also be seen in this graph. With the help of this diagram the happenings of figure 3 can be discussed. It can be seen that water cooling results in the hardest alloy. This is because when it is looked at the microstructure relatively high amounts of martensite can be seen. Martensite is very hard therefore the resulting steel is also very hard. For oil cooling martensite is once again formed but with lesser amount compared to water cooling. This results in the oil cooling being the next hardest AISI 1050 steel. Air cooling and Furnace cooling results in the formation of pearlite. Due to the faster cooling rate of Air cooling the pearlite is finer. It can also be said that finer pearlite is stronger than coarser pearlite therefore the steel that underwent air cooling is harder than furnace cooled steel. These conclusions are the reasons for figure 3.

The cooling rate can be determined by;

$$Cooling\ rate = \frac{Change\ in\ temperature}{change\ in\ time}$$

There is an affect on adding alloying elements. This affect for the TTT diagram can be seen as a shift of the curve. The curve shifts right and the need for the rate of cooling to form martensite is lessened. Meaning that martensite is more easily formed with the addition of an alloying elements and as a result the steel can become harder. Also, the martensite start temperature is decreased which can affect the amount of martensite that will form therefore the hardness. This can be contributed to the fact that the size of the austenite grains affects the shift for example for a coarse austenite grains, there is less nucleation sites for the beginning of pearlite transformation making the curve shift right (Ohring, 1995). These discussions are the answers on why AISI H13 is harder than AISI 1050 steel when they are both air cooled as it can be seen from figure 4 or even harder than oil cooled AISI 1050 steel.

CONCLUSION

In this experiment it was understood that by manipulating the process a material goes through one can play with its properties. The effect of carbon content, cooling medium and alloying element was observed. It can be concluded that the steel that has the higher carbon content was harder than the one with a lower one when heat treatment was done. This was attributed to the fact that the change in the carbon content affected the end result of the microstructure of the metal which affects the hardness. When the cooling mediums were observed it was seen that the faster the cooling the faster the steel became. This was once again due to the changes in the microstructure. Water quenched steel was the hardest and the furnace cooled steel was the softest. For the alloying element case, with the addition of more alloying element the TTT diagram shifts more which in the experiments case resulted in the easier capability to form martensite which made the steel harder. All in all, heat treatment is a very important process which is widely used in production. It allows one to change the properties of the materials as required by the engineering design cases.

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APPENDIX

ROCKWELL C (150 kgf. elmas uç)	ROCKWELL A (60 kgf. elmas uç)	ROCKWELL D (100 kgf. elmas uç)	SUPERFICIAL ROCKWELL 15N (15 kgf. elmas uç)	30N (30 kgf. elmas uç)	45N (45 kgf. elmas uç)	VICKERS (sertlik numarası)	BRINELL (3000kgf. 10mm karbür bilya)
68	85.6	76.9	93.2	84.4	75.4	940	...
67	85.0	76.1	92.9	83.6	74.2	900	...
66	84.5	75.4	92.5	82.8	73.3	865	...
65	83.9	74.5	92.2	81.9	72.0	832	**739**
64	83.4	73.8	91.8	81.1	71.0	800	**722**
63	82.8	73.0	91.4	80.1	69.9	772	**705**
62	82.3	72.2	91.1	79.3	68.8	746	**688**
61	81.8	71.5	90.7	78.4	67.7	720	**670**
60	81.2	70.7	90.2	77.5	66.6	697	**654**
59	80.7	69.9	89.8	76.6	65.5	674	**634**
58	80.1	69.2	89.3	75.7	64.3	653	615
57	79.6	68.5	88.9	74.8	63.2	633	595
56	79.0	67.7	88.3	73.9	62.0	613	577
55	78.5	66.9	87.9	73.0	60.9	595	560
54	78.0	66.1	87.4	72.0	59.8	577	543
53	77.4	65.4	86.9	71.2	58.6	560	525
52	76.8	64.6	86.4	70.2	57.4	544	512
51	76.3	63.8	85.9	69.4	56.1	528	496
50	75.9	63.1	85.5	68.5	55.0	513	481
49	75.2	62.1	85.0	67.6	53.8	498	469
48	74.7	61.4	84.5	66.7	52.5	484	455
47	74.1	60.8	83.9	65.8	51.4	471	443
46	73.6	60.0	83.5	64.8	50.3	458	432
45	73.1	59.2	83.0	64.0	49.0	446	421
44	72.5	58.5	82.5	63.1	47.8	434	409
43	72.0	57.7	82.0	62.2	46.7	423	400
42	71.5	56.9	81.5	61.3	45.5	412	390
41	70.9	56.2	80.9	60.4	44.3	402	381
40	70.4	55.4	80.4	59.5	43.1	392	371
39	69.9	54.6	79.9	58.6	41.9	382	362
38	69.4	53.8	79.4	57.7	40.8	372	353
37	68.9	53.1	78.8	56.8	39.6	363	344
36	68.4	52.3	78.3	55.9	38.4	354	336
35	67.9	51.5	77.7	55.0	37.2	345	327
34	67.4	50.8	77.2	54.2	36.1	336	319
33	66.8	50.0	76.6	53.3	34.9	327	311
32	66.3	49.2	76.1	52.1	33.7	318	301
31	65.8	48.4	75.6	51.3	32.5	310	294
30	65.3	47.7	75.0	50.4	31.3	302	286
29	64.6	47.0	74.5	49.5	30.1	294	279
28	64.3	46.1	73.9	48.6	28.9	286	271
27	63.8	45.2	73.3	47.7	27.8	279	264
26	63.3	44.6	72.8	46.8	26.7	272	258
25	62.8	43.8	72.2	45.9	25.5	266	253
24	62.4	43.1	71.6	45.0	24.3	260	247
23	62.0	42.1	71.0	44.0	23.1	254	243
22	61.5	41.6	70.5	43.2	22.0	248	237
21	61.0	40.9	69.9	42.3	20.7	243	231
20	60.5	40.1	69.4	41.5	19.6	[illegible]	226

Yukarıdaki tablolar, östenitik olmayan çelikler için Rockwell C bazında yaklaşık dönüşüm [illegible] verir. Koyu [illegible] F-10 ASTM Standartlarında Brinell testi için önerilen bölgenin dışındadır.

ROCKWELL B (100 kgf. 1/16" bilya)	ROCKWELL F (60 kgf. 1/16" bilya)	ROCKWELL A (60 kgf. elmas uç)	SUPERFICIAL ROCKWELL 15T (15 kgf. 1/16" bilya)	30T (30 kgf. 1/16" bilya)	45T (45 kgf. 1/16" bilya)	KNOOP (500 g & üstü)	VICKERS (SERTLİK NUMARASI)	BRINELL (3000 kgf. - 10mm bilya)
100	...	61.5	93.1	83.1	72.9	251	240	240
99	...	60.9	92.8	82.5	71.9	246	234	234
98	...	60.2	92.5	81.8	70.9	241	228	228
97	...	59.5	92.1	81.1	69.9	236	222	222
96	...	58.9	91.8	80.4	68.9	231	216	216
95	...	58.3	91.5	79.8	67.9	226	210	210
94	...	57.6	91.2	79.1	66.9	221	205	205
93	...	57.0	90.8	78.4	65.9	216	200	200
92	...	56.4	90.5	77.8	64.8	211	195	195
91	...	55.8	90.2	77.1	63.8	206	190	190
90	...	55.2	89.9	76.4	62.8	201	185	185
89	...	54.6	89.5	75.8	61.8	196	180	180
88	...	54.0	89.2	75.1	60.8	192	176	176
87	...	53.4	88.9	74.4	59.8	188	172	172
86	...	52.8	88.6	73.8	58.8	184	169	169
85	...	52.3	88.2	73.1	57.8	180	165	165
84	...	51.7	87.9	72.4	56.8	176	162	162
83	...	51.1	87.6	71.8	55.8	173	159	159
82	...	50.6	87.3	71.1	54.8	170	156	156
81	...	50.0	86.9	70.4	53.8	167	153	153
80	...	49.5	86.6	69.7	52.8	164	150	150
79	...	48.9	86.3	69.1	51.8	161	147	147
78	...	48.4	86.0	68.4	50.8	158	144	144
77	...	47.9	85.6	67.7	49.8	155	141	141
76	...	47.3	85.3	67.1	48.8	152	139	139
75	99.6	46.8	85.0	66.4	47.8	150	137	137
74	99.1	46.3	84.7	65.7	46.8	147	135	135
73	98.5	45.8	84.3	65.1	45.8	145	[illegible]	132
72	98.0	45.3	84.0	64.4	44.8	143	[illegible]	130
71	97.4	44.8	83.7	63.7	43.8	141	[illegible]	127
70	96.8	44.3	83.4	63.1	42.8	139	125	125
69	96.2	43.8	83.0	62.4	41.8	137	123	123
68	95.6	43.3	82.7	61.7	40.8	135	121	121
67	95.1	42.8	82.4	61.0	39.8	133	119	119
66	94.5	42.3	82.1	60.4	38.7	131	117	117
65	93.9	41.8	81.8	59.7	37.7	129	116	116
64	93.4	41.4	81.4	59.0	36.7	127	114	114
63	92.8	40.9	81.1	58.4	35.7	125	112	112
62	92.2	40.4	80.8	57.7	34.7	124	110	110
61	91.7	40.0	80.5	57.0	33.7	122	108	108
60	91.1	39.5	80.1	56.4	32.7	120	107	107
59	90.5	39.0	79.8	55.7	31.7	118	106	106
58	90.0	38.6	79.5	55.0	30.7	117	104	104
57	89.4	38.1	79.2	54.4	29.7	115	103	103

Figure 7. The converting table used to change HRB and HRC to HV