MEEN 160

MATERIALS SELECTION IN MECHANICAL DESIGN

EXPERIMENT #9

TEMPERING OF MEDIUM CARBON STEELS

By

Minster

I. Introduction

For each plain carbon and low alloy medium carbon steel the hardness and strength of the tempered steel depends on the tempering temperature-tempering time combination that it was subjected to. Experimentally, it is found that the overall tempering behavior of a given steel can be described by a plot of some property of the steel as a function of the parameter T ($14.3 + \log_{10}t$), where T is absolute temperature degrees Kelvin and t is time in seconds. In this experiment variations of the R_c hardnesses of quenched and tempered AISI/SAE 1045, 4140, and 4340 steels were followed experimentally as a function of tempering temperature and time in order to establish whether or not the overall tempering variations of hardness could be described as a function of the parameter T ($14.3 + \log_{10}t$) for each steel and to demonstrate the effect of substitutional alloy elements on tempering.

II. Experimental Procedures:

Our group was assigned two different steels that each had six specimens to be studied. The relevant composition limits were determined for the alloy elements present in AISI/SAE 4140, 4340, 6150, and 8620 steels and were recorded in the group data sheet. Before lab the TA austenitized the specimens for one hour at 850°C in an atmosphere furnace. After the time was up, the specimens were quenched in water to room temperature. Next, the specimens were attached to steel wires and tempered for 0, 1, 5, 15, 30, and 60 minutes in a salt bath and then water quenched. The temperature of the salt baths were measured and recorded in the group data sheet. After tempering the specimens were cleaned and then flat surfaces were ground on opposite sides in order to label the specimens and to prepare a surface for hardness testing. Five R_c hardness tests were made on one of the ground surfaces and the average was calculated along with the standard deviation. The values were recorded in the group data sheet.

III. Results

Table 1. Steel Composition Limits in Weight Percent

AISI/SAE	Alloy Element								
Number	Fe	C	Mn	Si	Cr	Mo	Ni	P_{max}	S_{max}
8620	Bal.	0.18/0.23	0.70/0.90	0.15/0.30	0.40/0.60	0.15/0.25	0.40/0.70	0.035	0.040
4140	Bal.	0.38/0.43	0.75/1.00	0.15/0.30	0.80/1.10	0.15/0.25	0.00	0.035	0.040
4340	Bal.	0.38/0.43	0.60/0.80	0.15/0.30	0.70/0.90	0.20/0.30	1.65/2.00	0.035	0.040
6150	Bal.	0.48/0.53	0.70/0.90	0.15/0.30	---	---	---	0.035	0.04

Table 2a. Hardness (Rc) Data for Tempered AISI/SAE 8620 Steel

Tempering Temp. (C)	Tempering Time (min.)											
	0		1		5		15		30		60	
	Hardness	Standard deviation	Hardness	Standard deviation	Hardness	Standard deviation	Hardness	Standard deviation	Hardness	Standard deviation	Hardness	Standard deviation
200	43.2		42.8				41.9				41.7	
243	41.8	2.3	42.6	1.2	43.7	1.2	42.8	1.0	41.5	1.5	42.7	1.2
294	42.8	1.5			38.0	0.4	40.8	0.9	42.1	1.1	35.3	3.5
347	43.2		40.9		39.0	0.8			39.5		38.2	
398	41.8	2.3	39.3	0.4	37.0	1.3	37.2	0.8	32.6	1.2	36.7	0.4
455	43.5	1.8	38.1	0.9	37.7	0.4	34.1	3.7	36.8	0.6	32.4	4.1
487	42.1	1.3	36.1	1.3	32.3	0.7	33.0	0.4	30.2	0.9	29.0	1.6
540	44.0	0.6	33.5	1.3	30.6	0.3	30.1	0.8	29.2	0.4		
588	40.3	2.0	27.1	2.9	26.2	0.9	25.5	1.2	21.5	6.7	20.5	3.8
637	41.8	0.9	26.8	0.9	24.0	0.8	18.7	3.9	21.1	3.1	20.3	0.6

Table 2b. Hardness (Rc) Data for Tempered AISI/SAE 4140 Steel

Tempering Temp. (C)	Tempering Time (min.)											
	0		1		5		15		30		60	
	Hardness	Standard deviation	Hardness	Standard deviation	Hardness	Standard deviation	Hardness	Standard deviation	Hardness	Standard deviation	Hardness	Standard deviation
200	53.5	1.5	51.8	2.0	51.9	2.1	50.3	0.8	51.4	0.4	49.4	0.6
243	55.2	1.9	51.0	1.0	54.1	1.3	51.2	2.1	48.6	1.6	46.3	0.5
294	55.6	2.2	44.0	3.0	43.6	2.7	46.1	3.3	44.9	3.0	47.4	1.7
347	51.7	1.5	45.2	1.3	44.8	1.1	44.3	0.4	45.6	1.0	44.8	1.0
398	55.2	1.9	44.1	0.5	41.8	0.9	42.1	1.3	43.3	0.5	42.7	1.5
455	55.9	1.5	46.1	0.7	42.8	0.9	41.8	0.8	37.4	5.5	43.3	1.1
487	54.3	2.6	43.8	0.3	39.7	0.5	38.0	0.6	39.1	0.8	40.3	0.4
540	55.0	1.4	39.2	0.9	36.8	1.6	36.7	0.8	36.7	0.3	36.5	0.4
588	57.0	3.4	36.4	1.0	35.7	0.4	33.7	0.7	32.9	0.7	32.0	0.6
637	56.9	0.8	38.8	0.9	32.6	0.8	30.7	1.1	26.8	1.9	28.0	1.9

Table 2c. Hardness (Rc) Data for Tempered AISI/SAE 4340 Steel

Tempering Temp. (C)	Tempering Time (min.)											
	0		1		5		15		30		60	
	Hardness	Standard deviation	Hardness	Standard deviation	Hardness	Standard deviation	Hardness	Standard deviation	Hardness	Standard deviation	Hardness	Standard deviation
200	54.8		56.8		52.4		50.3					
243	54.2	1.2	51.4	0.9	48.2	1.0	49.2	0.9	47.4	1.1	47.2	0.9
294	50.4	1.9	44.6	1.4	42.7	2.3	42.8	1.9	39.4	4.1	42.7	2.8
347	53.0	0.6	44.1	1.9	44.0		44.4	1.1	45.2	0.8	49.0	
398	54.2	1.2	43.6	0.5	44.0	1.3	43.6	1.1	42.3	0.9	43.6	0.4
455	54.9	1.4	45.5	0.4	44.1	0.1	42.5	0.6	41.3	0.5	42.0	0.6
487	52.9	2.2	42.8	0.5	40.8	1.6	37.9	0.8	38.5	0.7	36.0	1.3
540	56.0	0.7	41.2	0.5	41.5	1.4	38.0	0.7	36.2	0.4		
588	53.7	0.5	32.5	0.4	34.2	0.7	33.7	0.6	31.8	0.6	28.0	0.4
637	53.0	0.5	33.9	0.2	31.1	0.6	31.0	0.6	29.0	0.6	24.8	0.3

Table 2d. Hardness (Rc) Data for Tempered AISI/SAE 6150 Steel

Tempering Temp. (C)	Tempering Time (min.)											
	0		1		5		15		30		60	
	Hardness	Standard deviation	Hardness	Standard deviation	Hardness	Standard deviation	Hardness	Standard deviation	Hardness	Standard deviation	Hardness	Standard deviation
200	52.7		58.0		56.5		52.7		52.7		54.0	
243	55.8	0.5	53.2	1.5	51.0	0.7	52.3	2.4			51.7	1.4
294	61.4	0.4	52.8	0.6	51.0	0.9	52.7	0.7	52.2	0.7	48.2	0.5
347	51.7		48.8		47.8		46.7		45.7			
398	55.8	0.5	46.7	1.2	43.8	1.0	44.2	2.0	45.5	0.5	44.8	1.2
455	56.0	1.9	48.0	1.1	41.2	0.6	44.4	1.3	42.6	0.7	43.7	1.6
487	58.5	1.6	42.5	2.0	41.8	1.1	39.9	0.7	41.7	1.1	41.2	1.0
540	60.8	0.3	43.7	0.7	41.5	0.9	41.1	0.7	40.6	1.6	40.9	1.3
588	56.1	1.1	37.0	0.5	37.7	1.1	35.5	1.7	38.0	0.6	36.4	1.2
637	55.5	0.9	40.6	0.9	36.0	1.2	33.7	0.3	30.7	1.1	27.3	1.2

Table 3. Hardness vs. Tempering Parameter

Tempering Temp©	Temp. (K)	Time(min)	T(14.3+log t)	AISI/SAE 8620	AISI/SAE 4140	AISI/SAE 4340	AISI/SAE 6150
200	473	1	7604.966	42.8	51.8	56.8	58.0
200	473	5	7935.578		51.9	52.4	56.5
200	473	15	8161.257	41.9	50.3	50.3	52.7
200	473	30	8303.644		51.4		52.7
200	473	60	8446.031	41.7	49.4		54.0
243	516	1	8296.326	42.6	51.0	51.4	53.2
243	516	5	8656.995	43.7	54.1	48.2	51.0
243	516	15	8903.189	42.8	51.2	49.2	52.3
243	516	30	9058.521	41.5	48.6	47.4	
243	516	60	9213.852	42.7	46.3	47.2	51.7
294	567	1	9116.312		44.0	44.6	52.8
294	567	5	9512.628	38.0	43.6	42.7	51.0
294	567	15	9783.156	40.8	46.1	42.8	52.3
294	567	30	9953.84	42.1	44.9	39.4	
294	567	60	10124.52	35.3	47.4	42.7	51.7
347	620	1	9968.454	40.9	45.2	44.1	48.8
347	620	5	10401.82	39.0	44.8	44.0	47.8
347	620	15	10697.63		44.3	44.4	46.7
347	620	30	10884.27	39.5	45.6	45.2	45.7
347	620	60	11070.91	38.2	44.8	49.0	
398	671	1	10788.44	39.3	44.1	43.6	46.7
398	671	5	11257.45	37.0	41.8	44.0	43.8
398	671	15	11577.6	37.2	42.1	43.6	44.2
398	671	30	11779.59	32.6	43.3	42.3	45.5
398	671	60	11981.58	36.7	42.7	43.6	
455	728	1	11704.89	38.1	46.1	45.5	44.8
455	728	5	12213.74	37.7	42.8	44.1	48.0
455	728	15	12561.09	34.1	41.8	42.5	41.2
455	728	30	12780.24	36.8	37.4	41.3	45.5
455	728	60	12999.39	32.4	43.3	42.0	44.8
487	760	1	12219.39	36.1	43.8	42.8	42.5
487	760	5	12750.61	32.3	39.7	40.8	41.8
487	760	15	13113.22	33.0	38.0	37.9	39.9
487	760	30	13342.01	30.2	39.1	38.5	41.7
487	760	60	13570.79	29.0	40.3	36.0	41.2
540	813	1	13071.54	33.5	39.2	41.2	43.7
540	813	5	13639.8	30.6	36.8	41.5	41.5
540	813	15	14027.7	30.1	36.7	38.0	41.1
540	813	30	14272.44	29.2	36.7	36.2	40.6
540	813	60	14517.17		36.5		40.9
588	861	1	13843.29	27.1	36.4	32.5	37.0
588	861	5	14445.1	26.2	35.7	34.2	37.7
588	861	15	14855.9	25.5	33.7	33.7	35.5
588	861	30	15115.09	21.5	32.9	31.8	38.0
588	861	60	15374.28	20.5	32.0	28.0	36.4
637	910	1	14631.12	26.8	38.8	33.9	40.6
637	910	5	15267.18	24.0	32.6	33.1	36.0
637	910	15	15701.36	18.7	30.7	31.0	33.7
637	910	30	15975.3	21.1	26.8	29.0	30.7
637	910	60	16249.24	20.3	28.0	24.8	27.3

The microstructure of the as-quenched AISI/SAE 1045, 4140, 4340, 6150, and 8620 steels are

Discussion:

1. Increasing the tempering temperature of a medium carbon alloy steel decreases the hardness of the steel, namely the Rockwell C hardness. Increasing the tempering time of a medium carbon alloy steel also decreases the hardness of the steel.
2. Increasing the carbon content in the as-quenched medium carbon alloy steels increases the hardness of the steel. For example, for most cases, the AISI/SAE 6150 steel has the highest Rockwell C hardness values over the 4140, 4340 and 8620 steels because its carbon content is 0.50%, while the others have carbon contents of 0.40%, 0.40% and 0.20%, respectively. In tempering, increasing the carbon content in the as-quenched medium carbon alloy steels increases the softening of the steel and increasing the alloy content in the steel slows the rate of softening of the steel.
3. Substitutional alloy elements increase the hardness of the as-quenched martensite in the AISI/SAE 4140 and 4340 steels as increasing the alloy content in the 4140 and 4340 steels slow the rate of softening, making the steel remain harder for a longer time for a given temperature. It is indicated that in the selection of different low alloy steels, AISI/SAE 6150 should be selected on the basis of the hardness and strengths of the as-quenched steels.
4. Substitutional alloy elements in AISI/SAE 4140 and 4340 steels differ in that the 4340 steel contains Ni and the 4140 steel does not. There is very little difference in the hardness values of these two steels but overall the 4340 steel has higher Rockwell C hardness values. This is because the additional alloy element (Ni) increases the hardness of the as-quenched martensite of the 4340 steel.