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APPENDIX

Table 1A. Austenitizing temperatures for direct-hardening carbon steels (ASM Handbook)

Steel	Temperature, F
1025	1575-1650
1030	1550-1600
1033	1525-1575
1035	1525-1575
1036	1525-1575
1038	1525-1575
1040	1525-1575
1042	1475-1550
1043	1475-1550
1045	1475-1550
1048	1475-1550
1050	1475-1550
1052	1475-1550

Steel	Temperature, F
1055	1475-1550
1060	1475-1550
1064	1475-1550
1065	1475-1550
1070	1475-1550
1074	1475-1550
1078	1450-1500
1080	1450-1500
1084	1450-1500
1085	1450-1500
1086	1450-1500
1090	1450-1500
1095	1450-1500

Table 2A. Selection of frequency for induction heating of steel (Benningoff and Dsboron, 1945)

Hardened depth (mm.)	Dimensions (mm.)	Frequency					
		Commercial frequency 50-60 cps	Motor generator			Gap 20-100 kc	Vacuum tube 200 kc or higher
			1000 c	3000 c	10,000 c		
0.4-1.25	6-25					A	A
1.25-2.5	8-16				B	A	A
	16-25				A	A	A
	25-50			B	A	B	B
	25-50		B	A	A		
2.5-5.0	19-50			A	A	B	C
	50-100		A	A	B		
	100		A	B	C		
Through hardening	3-6					A	A
	6-12				B	A	A
	12-25			B	A	B	B
	25-50			A	A		
	55-100		A	A	B		
	100-200	B	A	B			
	200	A	A				

Note: (a) A. Optimum frequency, B. Suitable frequency, C. Passable

(b) Hardened depth means the depth of the layer hardened to the minimum of HRC 50 measured from the surface.

(c) Megacycle frequency is necessary for a depth smaller than 0.4 mm.

Table 3A. Effect of frequency on depth of case hardness (Benningoff and Dsboron, 1945)

Power input W/mm^2	Frequency KHz	Depth of hardening
15-19	450	0.5-1.1
8-12	450	1.1-2.3
15-25	10	1.5-2.3
15-23	10	2.3-3.0
15-22	10	3.0-4.0
23-26	3	2.3-3.0
22-25	3	3.0-4.0
15-22	3	4.0-5.0

Table 4A. (Source: Heat Treater's Guide of ASM)

Country		DEU	USA	JPN
Standard norm		DIN 17212-72	AISI	JIS G4051-79
Designation		Cf45	1045	S45C
Chemical composition	C	0.43-0.49	0.43-0.5	0.42-0.48
	Si	0.15-0.35	0.15-0.3	0.15-0.35
	Mn	0.5-0.8	0.6-0.9	0.6-0.9
	P	0.025	0.04	0.03
	S	0.035	0.05	0.035

Hot working and heat treatment

Forging	1100-850°C
Normalizing	850-870°C
Hardening	820-850°C (water quench)
	830-860°C (oil quench)
Tempering	550-650°C

Flame or induction hardening temperature will be 40-50 higher than hardening followed by water quenching

Stress relieving	150-180°C min., 1 h

Recommended Heat Treating Practice (From Heat Treater's Guide of ASM, 1982)

Normalizing: Heat to 1650 °F (900 °C). Cool in air.

Annealing: Heat to 1550 °F (845 °C). Cool in furnace at a rate not exceeding 50 °F (28 °C) per hour to 1200 °F (650 °C).

Hardening: It will be austenite at 1550 °F (845 °C) and can be quenched in water, brine or oil.

Tempering after hardening: Hardness of at least 55 HRC, if properly austenitized and quenched. Hardness can be adjusted by tempering.

Table 5A: End-Quench Hardenability. (Source: Metals Handbook, 9th ed., Volume 1, American Society for Metals, 1978)

Distance from quenched surface		Hardness (HRC)	
1/16 in.	mm	max	min
1	1.58	62	55
1.5	2.37	61	52
2	3.16	59	42
2.5	3.95	56	34
3	4.74	52	31
3.5	5.53	46	29
4	6.32	38	28
4.5	7.11	34	27
5	7.90	33	26
5.5	8.69	32	26
6	9.48	32	25
6.5	10.27	31	25
7	11.06	31	25
7.5	11.85	30	24
8	12.64	30	24
9	14.22	29	23
10	15.80	29	22
12	18.96	28	21
14	22.12	27	20
16	25.28	26	
18	28.44	25	
20	31.60	23	
22	34.76	22	
24	37.92	21	

Table 6A. All experiments result

Condition		Observation	Surface hardness	Case hardness (HV)															
Current (Amp)	Down speed (mm/sec)	No.	(HRC)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6
95	1.8	1	57.5	651	648	632	618	586	453	333	265	248	239	231	236	236	237	238	237
		2	57.5	651	647	635	617	586	456	331	264	247	235	237	238	235	237	238	236
		3	58	651	647	634	615	586	454	333	267	248	239	239	236	236	232	239	237
100	1.8	1	58	664	663	641	641	621	564	423	327	276	258	236	237	234	238	237	238
		2	58	664	664	640	642	621	561	422	328	278	257	238	236	237	239	238	236
		3	58.5	665	658	642	641	620	563	422	331	277	255	239	235	236	237	237	237
105	1.8	1	59	680	668	642	640	620	589	438	346	286	255	240	238	234	234	233	234
		2	59	679	667	643	641	622	591	438	347	286	255	241	238	232	234	233	234
		3	59	681	667	642	640	620	588	437	346	287	256	241	239	232	234	232	234
110	1.8	1	60	685	667	657	634	621	587	451	415	354	256	239	236	235	237	235	235
		2	59.5	685	667	655	635	620	589	451	416	355	259	241	234	236	239	234	235
		3	60	686	668	655	635	621	588	450	416	356	258	241	234	235	238	232	236
115	1.8	1	60.5	698	685	656	629	623	610	523	447	368	253	247	235	238	238	236	238
		2	60.5	697	684	658	628	622	611	521	446	369	253	247	236	234	237	235	234
		3	61	697	685	656	628	625	610	521	446	369	251	248	236	235	237	234	239

Table 6A (Cont.)

Condition		Observation	Surface hardness	Case hardness (HV)															
Current (Amp)	Down speed (mm/sec)	No.	(HRC)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6
120	1.8	1	61	698	695	674	663	628	612	558	461	369	329	248	236	237	236	236	239
		2	62	698	695	673	662	629	612	557	461	371	330	249	235	235	239	236	239
		3	62	697	694	673	662	628	611	556	462	370	331	249	235	236	239	237	239
125	1.8	1	62	699	685	678	652	631	614	559	478	375	331	241	237	239	236	236	235
		2	63	699	685	679	653	633	613	558	478	374	332	242	237	238	237	237	234
		3	62	698	683	679	653	631	614	558	479	372	332	241	238	237	238	235	235
105	2	1	58.5	652	649	645	610	584	342	309	271	249	238	238	236	238	236	237	238
		2	58	652	651	644	610	586	337	311	272	247	237	235	237	237	235	237	240
		3	58.5	653	652	642	613	583	340	312	273	247	238	237	236	240	235	239	237
105	1.9	1	58.5	674	652	648	625	624	536	318	295	254	241	237	235	236	235	235	238
		2	58.5	675	651	649	623	623	537	319	294	253	241	234	235	236	234	234	238
		3	59	675	652	649	627	623	534	317	296	254	242	235	237	234	239	236	237
105	1.7	1	59	677	671	657	644	637	612	557	422	287	257	247	237	238	238	234	234
		2	59	678	666	657	642	636	613	557	423	286	259	248	237	237	239	235	235
		3	59	679	667	659	644	636	612	558	422	286	257	248	237	237	239	236	235

Table 6A (Cont.)

Condition		Observation	Surface hardness	Case hardness (HV)															
Current (Amp)	Down speed (mm/sec)	No.	(HRC)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6
105	1.6	1	59	681	681	682	647	632	624	589	486	344	251	247	237	237	235	234	232
		2	59	682	681	683	647	633	623	589	487	343	251	248	238	237	235	235	233
		3	58.5	682	682	683	648	632	623	587	484	344	251	248	238	236	236	235	233
105	1.5	1	61	694	689	677	659	645	632	612	554	485	343	247	238	239	236	235	235
		2	60.5	694	690	677	658	645	631	612	556	487	341	246	239	238	236	234	234
		3	60.5	696	689	678	659	647	632	614	561	487	343	247	238	240	237	232	232
95	1.9	1	57	609	613	597	559	534	337	287	248	246	239	236	236	238	239	243	237
		2	57.5	611	608	596	562	538	341	284	247	237	241	239	236	241	237	239	236
		3	57.5	614	612	598	554	537	339	286	247	245	243	237	235	237	240	234	237
115	1.9	1	60	674	671	656	631	628	607	546	398	348	246	239	238	237	241	234	236
		2	60.5	681	679	653	634	629	612	539	397	351	245	233	241	238	238	236	237
		3	60.5	679	678	654	632	631	609	548	398	347	245	235	236	238	238	237	235
95	1.7	1	57.5	652	644	631	611	597	512	435	338	254	238	235	238	238	238	231	234
		2	58	653	645	632	615	596	514	441	329	253	236	234	237	237	236	235	234
		3	58	652	644	630	614	598	508	438	334	257	241	237	239	238	239	235	234

Table 6A. (Cont.)

Condition		Observation	Surface hardness	Case hardness (HV)															
Current (Amp)	Down speed (mm/sec)	No.	(HRC)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6
115	1.7	1	60.5	698	685	669	655	641	639	587	527	381	264	237	238	237	239	239	235
		2	61	697	685	670	661	643	641	584	528	379	261	237	237	235	238	235	239
		3	61	697	685	667	659	641	641	585	531	379	259	239	236	238	241	241	238
110	1.7	1	60	689	685	662	661	654	613	557	481	394	279	248	237	247	238	241	235
		2	59.6	691	685	661	661	658	621	554	475	391	276	251	239	236	246	237	236
		3	59.7	692	684	667	664	657	618	546	473	387	281	247	238	238	236	243	235

Table 7A Multiple Regression output of surface hardness

Y = surface hardness

C = current

S = down speed

Descriptive Statistics

	Mean	Std. Deviation	N
Y	59.0189	1.3009	9
C	105.0000	8.6603	9
S	1.8000	8.660E-02	9

Correlations

		Y	C	S
Pearson Correlation	Y	1.000	.981	-.165
	C	.981	1.000	.000
	S	-.165	.000	1.000
Sig. (1-tailed)	Y	.	.000	.335
	C	.000	.	.500
	S	.335	.500	.
N	Y	9	9	9
	C	9	9	9
	S	9	9	9

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.995[a]	.989	.986	.1554	.989	277.495	2	6	.000

a. Predictors: (Constant), S, C

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	13.394	2	6.697	277.495	.000[a]
	Residual	.145	6	2.413E-02		
	Total	13.539	8			

a. Predictors: (Constant), S, C

b. Dependent Variable: Y

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	48.019	1.323		36.305	.000	44.783	51.255					
	C	.147	.006	.981	23.231	.000	.132	.163	.981	.994	.981	1.000	1.000
	S	-2.483	.634	-.165	-3.916	.008	-4.035	-.931	-.165	-.848	-.165	1.000	1.000

a. Dependent Variable: Y

Table 8A Multiple regression output of hardness at 0.8 mm in depth

Y = hardness in depth at 0.8 mm

Descriptive Statistics

	Mean	Std. Deviation	N
Y	364.7400	92.1722	9
CURRENT	105.0000	8.6603	9
SPEED	1.8000	8.660E-02	9

Correlations

		Y	CURRENT	SPEED
Pearson Correlation	Y	1.000	.825	-.541
	CURRENT	.825	1.000	.000
	SPEED	-.541	.000	1.000
Sig. (1-tailed)	Y	.	.003	.066
	CURRENT	.003	.	.500
	SPEED	.066	.500	.
N	Y	9	9	9
	CURRENT	9	9	9
	SPEED	9	9	9

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.987[a]	.973	.965	17.3304	.973	110.147	2	6	.000

a. Predictors: (Constant), SPEED, CURRENT

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	66163.635	2	33081.817	110.147	.000[a]
	Residual	1802.055	6	300.342		
	Total	67965.689	8			

a. Predictors: (Constant), SPEED, CURRENT

b. Dependent Variable: Y

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	478.480	147.549		3.243	.018	117.443	839.517					
	CURRENT	8.783	.708	.825	12.414	.000	7.052	10.515	.825	.981	.825	1.000	1.000
	SPEED	-575.550	70.751	-.541	-8.135	.000	-748.671	-402.429	-.541	-.958	-.541	1.000	1.000

a. Dependent Variable: Y

VITA

My name is Therdsak Kangwarnyotsak, borne in January 6, 1975, Bangkok. My first degree is Industrial Engineering from Kasetsart University in 1997. After that I study at Chulalongkorn University in engineering management of the regional center for manufacturing system engineering for my master's degree.