International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075, Volume-3, Issue-5, October 2013

Thermo Mechanical Processing Of Hypereutectoid Steel Wire Rod in Lead Patenting

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Abstract - Lead patenting process is the most efficient way to transform hot rolled steel wire rod of different chemical composition into fine pearlitic steel. However, the optimization of various parameters of lead patenting process is critical to achieve high efficiency of transformation process in mass production of hypereutectoid steel wires. The experiment was conducted to find out the optimum range of austenitic temperature, lead bath temperature and phase transformation time. The effect of carbon percentage, size of steel wire rod and drawn strain prior-to-patenting on mechanical properties are also observed through various experiments and evaluated.

KEY WORDS: Tensile strength; Torsion strength; Hypereutectoid steel; Lead patenting process.

I. INTRODUCTION

Lead patenting process is the most efficient process used to transform phase of hypereutectoid steel. The critical parameters of this process are austenitic temperature, Lead Bath temperature and transformation time which affect the efficiency of process. The other parameters which affect output of the lead patenting process are the quality of material and the size of material. Hypereutectoid steel wires are used where high strength, wear resistance, ductility, toughness and low cost are important. Hypereutectoid steel wires are among the strongest available bulk material with tensile strength currently above 5 GPa Wires used for bridges have strength of 1250 – 1800 MPa Wires used for cord wire of tires have strength of 2750 – 4500 MPa The springs steel wires used for major applications have strength of 1500 – 3500 MPa.

The strength of steel increases with increase in carbon content and it is governed by Hall-Petch relationship.

$$\sigma = \sigma_o + K\,\lambda^{-1/2}, \qquad (1)$$

Where,

σ is stress

σ_o is frictional stress

K is Hall-Petch constant

λ is interlamellar spacing in pearlitic steel.

The Nippon Steel Corporation, Japan[1-4] studied the effects of austenitic temperature, lead bath temperature and transformation time of hypereutectoid steel having 0.82 % carbon(C), 0.84 % Manganese (Mn) and 0.92 % C, 0.91 % Mn. The interlamellar spacing decreases with increase in carbon content.

Manuscript received October, 2013.

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The same has been experimentally found correct. The effect of carbon content on Hall-Petch parameter studied by W. J. Nam et al [5] and Choi & Park [6], The effect of chromium on strength investigated by T. Tarui et al [7], M. Munirajulu et al [8], D.B. Park et al [9] and H. R. Song et al [10] and found that chromium reduces the interlamellar spacing of pearlite. Similarly, the effect of silicon (Si) and vanadium (V) has been investigated by K. Han et al. [11] and found that vanadium reduces the grain size of pearlite. Si & V both suppresses the formation of a network of continuous grain boundary cementite. Xu Jin-qiao et al [12] developed the model for interlamellar spacing in pearlite colony of 0.82 % C, 0.84 % Mn. Caballero [13] developed the model for interlamellar spacing in pearlite colony of 0.76 % C, 0.91 % Mn. Elawazri et al [14] carried out experiment at static condition in laboratory to provide sufficient time for austenitization and also sufficient time for full transformation of austenite into pearlite. However, in mass production of wires, practically, it is not economical and feasible to provide such long time for austenitization and transformation. The cent-percent efficiency of transformation in mass production is not feasible. So, optimization of lead patenting process is studied in this paper. It mainly deals with the optimization of following parameters in lead patenting process to obtain best mechanical properties.

- Effect of austenitic temp. on mechanical properties
- Effect of transformation temperature on mechanical properties.
- Effect of transformation time on mechanical properties
- Effect of cross sectional area on mechanical properties.
- Effect of composition of wire rod on mechanical properties
- Effect of drawn strain prior-to-patenting on mechanical properties.

II. EXPERIMENTAL PROCEDURE

2.1 Material Condition and Processing

Steel used in this study is hot rolled wire rods of different dia. with chemical composition mentioned in table-1.

Table 1

Chemical composition (wt, %) of steelsSteel	Carbon	Manganese	Silicon	Sulphur	Phosp-horus	Chrom-ium	Nic-kel	Cop-per	Alum-inium
A	0.87	0.57	0.16	0.010	0.070	0.01	0.01	0.02	0.10
B	0.82	0.70	0.19	0.008	0.017	-	-	0.01	-
C	0.79	0.60	0.20	0.008	0.014	0.04	0.01	0.02	-

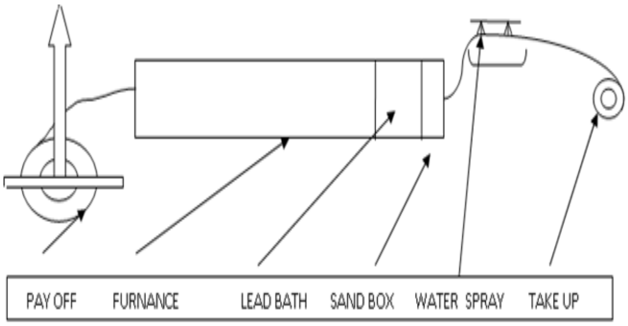


Fig. 1. Sketch of Lead patenting furnace

The experiment conducted on an electric powered furnace of 17.1 meters length, which consists of 4.8 meter long lead bath. The mass of lead in lead bath is sufficiently large to avoid the effect of increase in temperature of lead bath due to submergence of hot austenitic wire rod. The sketch of experimental setup is shown in figure 1.

Hot rolled wire rods of steel are grinded on centre-less grinder to remove the dust, surface defects and decarburized layer. The coil is then anneals to remove the grinding stresses and is allowed cooling in air up-to ambient temperature. The coil is then placed in pay-off. The furnace consists of high temperature resistant alloy's seamless tube through which wire rod passes. The furnace consists of six heating zones. The lead bath is covered with charcoal-ash to reduce oxidation of lead and restrict the generation of fumes as well as to restrict heat loss. The temperature of lead bath varies from 480 ^{0}C to 600 ^{0}C to study the effect of transformation temperature on

mechanical properties of wire rod.

The time required per revolution of capstan of diameter D is = 3.14 x 60 D x d /17100 seconds.

So, the average speed of wire is = 17100 N / 60d.

Where, d is diameter of wire rod to be patented.

D is diameter of capstan on which wire is wrapped.

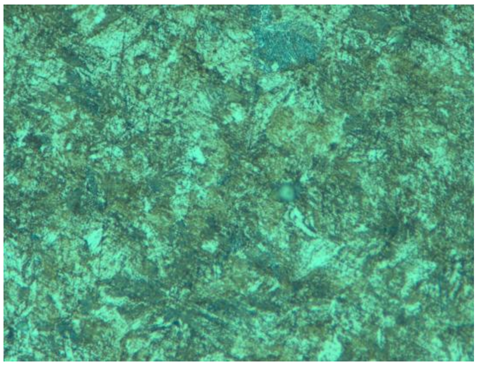
N is no.' s. of revolution of capstan per second.

2.2. Mechanical Properties Measurement

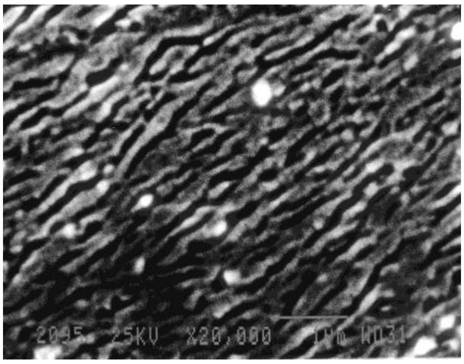
The mechanical properties of lead patented wire rods have been evaluated after keeping sufficient idle time for patented wire rods to get in stable conditions. The mechanical properties measured are ultimate tensile strength (UTS), torsion strength and reduction in area (RA). The average values of mechanical properties of both ends of coil are taken to reduce error in experiment. The tensile strength test is carried on universal testing machine as per IS- 1608:1995. Similarly, torsional strength test is carried out on different torsion testing machines of suitable diameter as per IS-1717:1985

2.3. Microstructure analysis techniques

Isothermally transformed wire rod samples at different lead temperature and furnace temperature are prepared for optical microscopic study by mounting on Bakelite and then grounded on silicon carbide emery paper of size ranging from 60 grits to 2000 grits. Finally, polished with 9 micron, 3 micron, 1 micron water based diamond suspensions on very fine cloths. The samples are etched with 3 % natal.



a



b

Fig. 2. (a) Optical image at 1000 X magnification & (b) SEM image at 20,000 X magnification of 'steel A' wire rod of 4.0 mm diameter austenitised at 950 ^{0}C & transformed at 520 ^{0}C.

The samples for SEM examination have 5 mm length. The samples preparation method adopted for SEM examination is same as mentioned earlier for optical microscopic examination. Finally the samples are dried in desiccators and then they are gold plated before scanning. Figure 2 (a) and 2 (b) show the image of steel A at 1000 X and 20000 X magnification respectively.

III. RESULTS AND DISCUSSION

3.1 Effect of Austenitic Temperature on Mechanical Properties

To investigate effect of austenitic temperature on patented wire rods, the furnace temperature i.e., austenitic temperature is maintained at 950 ^{0}C and 1050 ^{0}C. Result obtained for steel A wire rod size 4.00 mm diameter and constant transformation time is mentioned in table 2.

Table 2 Effect of austenitic temperature on UTS, RA and Torsion.

Austenitic temp. (^{0}C)	Lead temp.(^{0}C)	UTS (N/mm^2)	RA (%)	Torsion (Nos.)
950	500	1402.51	37.00	21.5
950	540	1364.63	37.95	25.0
950	580	1327.07	34.20	31.5
1050	500	1341.68	33.45	17.0
1050	540	1256.28	32.25	17.0
1050	580	1205.97	27.00	22.0

Results indicate that higher austenitic temperature leads to high average grain size. If grain size is higher than patented wire rod will have lower UTS due to lesser boundary area and lower reduction in area due to formation of strong cementite network along grain boundary. Number of turns before failure in torsion test will be less because of presence of cementite network at grain boundary. At very low austenitic temperature, homogenization in material becomes improper. So, austenitic temperature of 950 ^{0}C leads to optimum results.

3.2 Effect of Transformation Temperature on Mechanical Properties

The transformation of austenite into pearlite takes place in lead bath. To investigate the effect of transformation temperature, the temperature of lead bath varies from 480 ^{0}C, 500 ^{0}C, 520 ^{0}C, 540 ^{0}C, 560 ^{0}C, 580 ^{0}C and 600 ^{0}C. The table 3 shows the mechanical properties of steel B belong to patented wire rod of 3.00 mm diameter, which is austenitised at 950 ^{0}C and transformation time kept constant.

Table 3 Effect of lead bath temperature on UTS, RA & Torsion.

Austenitic temp. (^{0}C)	Lead temp. (^{0}C)	UTS (N/mm^2)	RA (%)	Torsion (No.'s)
950	480	1364.5	45.45	30
950	500	1373.95	46.45	31.5
950	520	1374.63	39.1	42.5
950	540	1360.21	39.65	21
950	560	1311.94	37.55	36
950	580	1297.14	40.05	43

The transformation temperature has finest effect on the mechanical properties of patented wire rods. As temperature of lead bath increases keeping all other parameters constant, the UTS of patented wire rods increases slightly and then decreases with increase in lead temperature. At lower transformation temperature, the diffusion of carbon becomes sluggish but the degree of under cooling increases. At higher temperature, the diffusion of carbon becomes fast but the degree of under cooling decreases drastically. Hence, net transformation becomes small at high lead temperature. So, the optimum lead temperature is one at which highest transformation of austenite in to fine pearlite takes place.

3.3 Effect of Transformation Time on Mechanical Properties

The transformation time is the time difference between the enter and exit of wire rod from lead bath. The temperature of lead remains uniform throughout the lead bath. So the transformation occurred at constant temp.

The average transformation time (ATT) is determined as: Average time/ revolution = (3.14 x D x 60) / Factor Q.

Where, Factor Q = Length of heating zone of furnace including lead bath (in mm) / wire rod diameter.

D = diameter of capstan

d = diameter of patenting wire rod in mm.Linear speed of patenting wire rod (in mm /min) = 3.14 x diameter of capstan x numbers of revolutions per minute.

ATT = length of lead bath (in mm) / linear speed of patenting wire rod. The effective length of lead bath is 4000 mm. The take-up system of patenting furnace consists of 3 different diameters, i.e., 750mm, 550mm & 450mm. The capstan of 750 mm is used to handle wire rod of diameter from 7.00 mm to 5.00. The capstan of 550 mm is used to handle wire rod of diameter from 5.00 mm to 2.00 mm. The capstan of 450 mm is used to handle wire rod of diameter from 2.00 mm to 1.00 mm. ATT for wire rod of diameter 7.00 mm, 6.00mm, 5.00 mm, 4.00 mm, 3.00 mm, 2.00 mm and 1.00 mm is 98.24 second,84.21 second, 70.20 second, 56.12 second, 42.09 second, 28.05 second and 14.03 second respectively.

The experiment is carried out to investigate the effect of mechanical properties by varying the transformation time from ATT. The table 4 shows the output of experiment for wire rod of 3.00 diameter, austenitized at 950 ^{0}C and lead temperature at 540 ^{0}C for steel B with varying ATT.

Table 4 Effect of ratio of ETT & ATT on UTS, RA & torsion.

ATT (Sec.)	ETT (Sec.)	ETT/ ATT	UTS (N/mm^2)	RA (%)	Torsion (No.'s)
42.09	25.25	0.60	1347.97	36.8	30.5
42.09	33.67	0.80	1321.39	35.8	28.0
42.09	42.09	1.00	1360.21	39.65	21.0
42.09	50.51	1.20	1355.02	38.00	32.5
42.09	58.93	1.40	1309.54	43.35	28.0

Experimental results indicate that there is decrease in UTS, reduction in area and torsion when ETT/ATT is less than one because amount of phase transformation from austenite to pearlite decreases due to shortage of transformation time. When ETT / ATT is more than one then there is decrease in mechanical properties. As the speed of wire decreases, submergence of austenitised wire in lead bath is delayed, so, cooling rate decreases.

3.4 Effect of Cross- Sectional Area of Patenting Wire Rod on Mechanical Properties

The experiment is conducted on wire rod of cross-sectional area ranging from 5.50 mm, 4.00 mm, 3.00 mm and 2.00 mm. As the cross sectional area of wire increases, the ATT increases proportionally. The increase in ATT along with wire diameter is due to increase in time required for soaking time. Table 5 shows the results of experiment belonging to steel B austenitised at 950 ^{0}C, lead bath temperature at 500 ^{0}C and transformation time kept equal to ATT.

Table 5 Effect of diameter on the UTS, RA and torsion

Diameter of wire (mm)	UTS (N/mm^2)	Reduction in area (%)	Torsion (No.'s)
2.0	1376.47	55.5	51.5
3.0	1373.63	47.9	39.5
4.0	1367.06	43.3	27.0
5.5	1326.24	34.15	10.0

The result indicates that with increase in diameter of wire rod, the UTS and reduction in area of patented wire decreases. Torsion decreases at faster rate as compare to UTS or reduction in area. This effect is known as sizing effect.

3.5 Effect of Drawn Strain Prior-to-Patenting In Patented Wire Rod on Mechanical Properties

To study the effect of wire drawing strain prior- to-patenting, the initial diameter of wire rod is kept at 5.50mm in first sample, which has no prior-to- patenting wire drawing strain. Second, third and fourth sample is subjected to wire drawing strain. Table 6 shows the results of experiment of steel B austenitised at 950 ^{0}C, lead bath temperature at 500^{0}C and transformation time kept equal to ATT.

Initial drawn strain is calculated as: Initial drawn true strain, $e_d = \ln (e)^2$

Where, e- engineering strain

e = final drawn diameter / original diameter

Table 6 Effect of initial drawn true strain on UTS, RA & Torsion

Diameter of wire (mm)	Engineering strain, e	Initial drawn true strain, e_d %age	UTS (N/mm^2)	RA (%)	Torsion (No.'s)
5.5	0.00	0.0000	1326.24	34.15	10.0
4.0	27.27	0.6369	1367.06	43.3	27.0
3.0	45.45	1.2122	1373.63	47.9	39.5
2.0	63.63	2.0232	1376.47	55.5	51.5

It is concluded that with increase in initial drawn true strain the UTS of patenting wire rod increases. It is mainly due to higher elongation of grain, smaller grains are formed during patenting. So, it leads to better mechanical properties after patenting.

The similar result is shown by sizing effect analyzed in paragraph 3.4. So, it is not possible to separate the effect of drawn strain prior-to-patenting or sizing effect with these results.

3.6 Effect of Chemical Composition of Patenting Wire Rod on Mechanical Properties

The experiment is carried out on three types of steels of different chemical composition. The detail chemical composition is mentioned in table-I. The results of experiments shown in table 7 belong to these steels austenitised at 950 ^{0}C, lead bath temperature at 520 ^{0}C and transformation time kept equal to ATT.

Table 7 Effect of carbon content on UTS, RA and torsion

Type of steel	Carbon %age	UTS (N/mm^2)	Reduction in area (%)	Torsion (No.'s)
Steel A	0.87	1376.47	55.5	51.5
Steel B	0.82	1373.63	47.9	39.5
Steel C	0.79	1367.06	43.3	27.0

It is concluded that carbon percentage in steel has direct effect on the mechanical properties during lead patenting process. UTS, RA and Torsion increases with increase in carbon percentage in steel. This is due to decrease in interlamellar spacing between ferrite and cementite.

IV.CONCLUSIONS

- The austenitic temperature at 950 ^{0}C in lead patenting process gives the best results due to formation of smaller average grain size, higher boundary surface area which acts as dislocation movement barrier.
- The transformation temperature should be kept at 520 ^{0}C for wire rod diameter below 4.00 mm & 500 ^{0}C for wire rod diameter above 4.00 mm.
- The transformation time should be kept equal to average transformation time.
- The lower cross section area of wire rod leads to superior mechanical properties as compared to wire rod of higher cross sectional area.
- The higher drawn strain prior-to-patenting leads to better mechanical properties.
- The higher percentage of carbon in chemical composition of steel results in better mechanical properties.

ACKNOWLEDGEMENTS

The authors are thankful to the PEC University of Technology, Chandigarh and the Ordnance Cable Factory, Chandigarh for their support.

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