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Identification of Effective Low Temperature Treatment to Improve Wear Resistance of S1 Steel

[1]P Sekhar babu, [2]P Rajendran
[1]Professor & Principal, Siddhartha Institute of Engineering & Technology, Vinobha Nagar, Ibrahimpatnam, Hyderabad, Telangana. 501506
[2]Researcher Osmania University, Hyderabad 500007
E-Mail : [1]psbabu12@gmail.com, [2]pichakannu@yahoo.com

ABSTRACT
In this work the authors have studied the improvement in wear resistance of a shock resisting steel(S1) tool steel by Cryogenic Treatment. The material is tested for improvement in abrasive wear resistance by treating cryogenically at different temperatures below 0^0 C. All the specimens are first heat treated as per standard norms and re tempered after Cryogenic treatment. The specimens are treated at -40^0 C, - 80^0 C, -150^0 C and at -190^0 C. Wear resistance is tested by sliding wear method (Pin-on-Disk). The overall percentage improvement of wear resistance of S1 steel at cold treatment I was 112%, cold treatment II was 140%, cryotreatment I was 202% and cryotreatment II was 200%, so it is suggested that S1 steel can be treated under cryotreatment I condition.

KEYWORDS: Cryogenic Treatment, Microstructure, Wear Resistance

INTRODUCTION

S-1 is a medium carbon shock-resisting steel combining moderate hardness with good toughness characteristics. It is a deep hardening, oil quenching steel designed for shock and impact applications such as chisels, pneumatic tools, shear knives, and punches. The nominal value of S-1steel composition as per AISI (1978) and actual composition was found by wet type method is listed in Table 1.

EXPERIMENTATION

In the Pin-on-Disk apparatus [10] the maximum size of pin that can be accommodated is held as ϕ6 mm and 50 mm length. The specimens were machined to ϕ5 and a length of 30mm. Then the pieces were faced flat and made to contact fully on the disk (grinding wheel GC 320 K5V). Finally the specimens were finished by centreless grinding to avoid irregularity in their diameters.

Cold treatment and Cryotreatment were introduced after completion of hardening process. In case of cold treatment, one part of hardened and stress relieved samples were cooled from room temperature of 30ºC to -40ºC and another set of samples were cooled from room temperature to -80ºC in 2 hours and 4 hours respectively then soaked at this temperature for 24 hours. Subsequently the samples were slowly heated to room temperature in 1 hour and 2 hours respectively.

In case of Cryotreatment, one set of hardened and stress relieved samples were cooled from room temperature of 30ºC to -150ºC and another set of samples were cooled from room temperature to -190ºC in 6 hours and 8 hours respectively then soaked at this temperature for 24 hours. Subsequently the samples were slowly heated to room temperature in 4 hour and 6 hours respectively.

On completion of all the Heat treatment process, Treatment conditions considered for wear resistance are recorded as:

1. Untreated **[NORMAL]** (Hardened & Tempered)
2. Coldtreated - I **[C1]** (Hardened + Cold treated at -40ºC (233K) + Tempered)
3. Coldtreated - II **[C2]** (Hardened + Coldtreated at -80ºC (193K) + Tempered)
4. Cryotreated - I **[CR1]** (Hardened + Cryotreated at -150ºC (123K) + Tempered)
5. Cryotreated - II **[CR2]** (Hardened + Cryotreated at -190ºC (83K) + Tempered)

The surface of the component does not resist abrasion with the result that it cannot be used in applications where it must resist wear, such as gear, cam, shaft etc. Attempts to harden the surface, such as carburizing, have met with limited success. Due to the carburizing, the diffusion of the carbon alone produces resistance to abrasion after hardening. This happened because carbon molecules fill in to the base material as an interstitial solid solution. To produce a hard wear-resistant surface, steel has been treated of different conditions.

This study aims to characterise by identifying the quenching temperature of heat treatment processes. Hence the specimens were treated stage-by-stage to cryotreatment namely Normal, C1, C2, CR1 and CR2 and maintained for 24 hours soaking period for all the categories. Microstructures were characterised by metallographic examinations and hardness measurements. The hardness was measured at the end of each heat treatment process. Finally the hardness of five classified samples were tabulated in Table 2

PIN-ON-DISK WEAR TEST

The method describes a laboratory procedure for determining the wear of materials during sliding using a Pin-on-Disk apparatus [10]. Materials are tested in pairs under abrasive conditions. The wear test of the tool steels were carried out by changing the following parameters.

1. Load acting over the pin (20 N, 30 N, and 50 N)
2. Linear velocity of the pin by adjusting the rpm and radial distance
3. Continuous sliding time (5, 10 and 15 minutes)

The wear test was conducted for three separate sliding timings for the speed of 130 rpm, 20 N and weight loss readings were noted down for each pin with respect to travel timing. Then the rpm was set to 200 and 280 and the same procedure was repeated for each case. Subsequently the wear test was conducted for 30 N and 50 N loads.

The same procedure was followed for the wear test on untreated, Coldtreated [C1, C2] and Cryotreated [CR1, CR2] specimens and the results were tabulated in Table No. 3

STUDY OF S1 STEEL WITH DIFFERENT LOW TEMPERATURE TREATMENT

S1 steel is a medium carbon content of 0.5% and less alloy of tungsten 2.5% and chromium 1.5%. Since the driving force was migration of carbon and formation of new carbide by low temperature treatment, hence, the specimens were treated stage-by-stage to cryotreatment namely Normal, C1, C2, CR1 and CR2 and maintained for 24 hours soaking period for all the categories.

From the microstructure of S1 steel show in figure from 1 to 5, it can be seen that, in cryogenic treatment and cold treatment II, the atomic spacing with in the freshly formed martensite decreases by the degree of cooling. This influenced the migration of carbon to fill the developed voids during the transformation of retained austenite to martensite. The particle size distributed in Normal, C1, C2, CR1 and CR2 were not similar, so that size and shape of the elements were reduced and newly formed carbides were precipitated in the entire material.

The maximum amount of transformation of retained austenite to martensite took place at C2 treatment. Cryogenic treatment further reduced the presence of retained austenite to nearly negligible value. The level of retained austenite presented in the steel was evaluated and shown in figure 6 and also it can be seen in the microstructure of S1 steel. Cryogenic treatment was also responsible for the formation of secondary carbide to create more toughness to the material, so that hard martensite structure was formed. The precipitation of fine carbides and formation of secondary carbide as a result of treatment was accountable for the improved wear resistance.

The temperature at which transformation of austenite to martensite started during cooling, it was observed that longer the holding time, that more it helped the surface to get uniform temperature, which produced different thermal contraction as well as dislocation in the structure. Hence the formation of martensite required to be cooled below a certain temperature in order to develop internal stress to an adequate amount so as to generate crystal defects. It influences dispersion of carbon molecules to fill in the voids.

Figure 7 shows overall percentage improvement of wear resistance with respect to the level of retained austenite in the material due to different low temperature. In Normal treatment, there was no cluster of carbides present in the structure. In case of C1 due to the cooling of the retained austenite which just started to transform into martensite, which can also be seen as formation of boundary structure in the microstructure. Moreover, the formation of carbide as well as migration of carbon did not yet start. But in case of C2, almost maximum amount of retained austenite got transformed into martensite. At the same time, formation of secondary carbides did not yet take place. This indicated that improvements of wear resistance, developed by the transformation of retained austenite and hence less improvement of wear resistance generated in C2 treatment.

In CR1, the improvement of wear resistance was **maximum** with little amount of reduction in retained austenite compared to C2. This result shows that the improvement of wear resistance was not only the transformation of retained austenite; it indicated other functions that had taken place in the material under cryogenic treatment. Cryogenic treatment developed formation of secondary carbides, which resulted homogeneous, super saturated martensite structure.

Since the material was a low carbon and low alloy elements, the development of new carbides, migration of carbon molecules and transformation of retained austenite into martensite were saturated in the CR1 treatment itself. There was no further development of carbide that could possibly take place in CR2 condition but major amount of retained austenite was reduced. These changes of retained austenite in CR2 created unfilled voids in the surface, so that improvements of wear resistance were reduced as compared to CR1 condition. S1 steel should be treated at CR1 condition which results increased tool life.

Macro residual stresses were relieved during the stress relieving process. But it does not get relieved completely by this stress relieving process. Thermal generated residual stresses that occurred during the hardening and remained at that state at room temperature at which the material yield stress reduces generally gets reduced. Hence the evaluation of residual stresses present in the tool was important to estimate the life of tool. Subjecting the specimen at low temperature could eliminate residual stress. The level of residual stress present in the specimen for all low temperature treatment was evaluated and shown in figure 8. High tensile residual stress was found in NORMAL and C1 treatments. But in case of C2, residual stress was reduced by a considerable amount. However, Cryogenic treatment drastically reduced the residual stress formed in the steel and only a meager difference was observed between CR1 and CR2. Since the %retained austenite and residual stress were of a smaller amount in CR1 treatment, wear resistance was improved to maximum when compared to Normal treatment, cold treatment and CR2.

WEAR RATE OF S1 STEEL WITH DISTANCE TRAVELED

The experimental data at figure nos. 9, 10 and 11 lists the trend in abrasive wear behaviour of Normal treatment, cold treatment and cryogenic treatment of S1 specimen with different load, linear velocity and duration.

With load 20N at 13.77 m/min velocity the wear rate was lower for CR1 and CR2 than the Normal treatment. The wear rate of cryotreatment CR1 and CR2 were same from 140 m onwards. In case of load of 20 N at 21.19 m/min and at 29.66 m/min gave same wear rate on cryotreatment CR1 and CR2. Hence the CR1 was more suitable for 20 N load for all linear velocities than other sub-zero treatments.

The wear rate of CR1 was lesser than CR2 for all speeds of 13.87 m/min, 21.34 m/min and 29.88 m/min at constant load 30N. Hence the CR1 was more suitable for 30 N load for all linear velocities than other low temperature treatments. Load 50 N at 8.56 m/min, 13.17 m/min and 18.44 m/min linear speeds, the wear rate pattern was as equivalent to wear rate of 20 N load. And the wear rate was same for CR1 & CR2 specimens.

Fig 9 to fig. 11 shows the bar graphs of overall percentage improvement of wear resistance in S1 steel at 20 N, 30 N and 50 N loads respectively. The maximum percentage improvement was obtained at CR1. The overall enhancement of wear resistance compared to Normal treatment in each case was 12%, 40%, 102% and 100% for C1 (233 K), C2 (193 K), CR1 (123 K) and CR2 (83 K) respectively. The maximum improved wear resistance was experimentally evaluated in cryogenically treated specimens because of the development of toughness and formation of uniform hardness surface, which could influence the longer tool life. Hence, this evaluation study of cryogenic treatment resulted into maximum development that happened at CR1 treatment condition.

SPECIFIC WEAR RATE OF S1 STEEL WITH LINEAR VELOCITIES

From the observation at Table No.3, it was observed that as the linear velocity increases, the specific wear of specimen at 20 N, 30 N and 50 N load decreases for all categories of specimens and specific-wear pattern was same at all loads for CR2 specimen. The gap of specific wear between Normal treatment and Cryotreatment was quite large for all cases.

Figures 12 to 14 show the bar graph of overall percentage of specific wear in S1 for the load of 20 N, 30 N and 50 N respectively. CR1 and CR2 show almost equivalent performance in all cases. **The maximum specific-wear resistance was obtained at cryotreatment I (CR1).** The overall enhancement of specific-wear resistance compared to normal treatment in each case was 12%, 40%, 102% and 100% for C1 (233 K), C2 (193 K), CR1 (123 K) and CR2 (83 K) respectively.

Figure 15 shows the overall specific wear rate of S1 steel specimen in different treatment condition with respect to axial load, which was evaluated from the observation table. It was understood that the treatment condition plays a vital role in the material to resist metal loss with respect to load applied on. Wear rate of NORMAL was 2.01, 2.19 times at 20 N, 1.81 & 1.52 times at 30 N and 2.17 & 2.04 times at 50 N approximately higher than of CR1 & CR2 respectively. Also, the wear rate of NORMAL was 1.47 times at 20 N, 1.33 times at 30 N and 1.37 at 50N times approximately higher than C2. These improvements happened in cold treatment was more or less the same for all loads. It indicates that improvement of wear resistance had taken place only by the transformation of retained austenite into martensite; where as in case of CR1 and CR2, wear resistance still improved due to the formation of secondary carbides under low temperature. Experimental results show that specific wear rate pattern was uniform and path of CR1 and CR2 almost got merged together for 20N and 30N loads. Cryogenic treatment did produced maximum improvement of wear resistance for 20N and 50N loads.

As a result of this work, the difference in level of percentage-retained austenite and residual stress between CR1 & CR2 was marginal; the experimental results show the same overall percentage of wear resistance improvement in CR1 & CR2. Hence S1 steel should be treated under Cryotreatment I (CR1) condition.

STUDIES OF S1 STEEL MICROSTRUCTURE WITH DIFFERENT LOW TEMPERATURE TREATMENTS

Figures 1 to 5-show microstructure of S1 steel used in this investigation, consisted of a Fe- rich matrix with 0.5% of C, and low alloy of Tungsten and chromium carbides. This was apparent from the microstructure taken at 1000X, the dark block spots (bigger in size) were indicative of Fe distribution, white colour spots were that of carbide distribution and rest was carbon distribution. The transformation of retained austenite into martensite can be seen in the Cold treatment C1.The size and shape of carbides is reduced to maximum up to the cold treatment. The number of alloy carbides (Chromium carbide bright white spots) were formed, and were more uniform and rounded in shape, martensite matrix appeared more homogeneous and saturated at CR1 treatment condition. The microstructure of CR2 was not showing any further development of chromium carbides, but carbide precipitation had taken place. As compared to the structure under normal treatment and cold treatment, the cryogenic treatment CR1 had shown larger number of secondary carbides, which resulted in to the uniform hardness and toughness on the surface. The structure of cryotreatment at –150ºC shows more homogenity than structure of cryotreatment at –190ºC.

CONCLUSION

1. The maximum percentage of life improvement obtained in S1 steel at cold treatment I was 140% at 20 N, 21.19 m/min, cold treatment II was 180% at 20 N, 21.19 m/min, cryotreated I was 250% at 20 N & 50 N, 29.66 & 8.56 m/min respectively and cryotreated II was 300% at 20 N, linear velocity of 13.77 m/ min.
2. The overall percentage improvement of wear resistance of S1 steel at cold treatment I was 112%, cold treatment II was 140%, cryotreatment I was 202% and cryotreatment II was 200%, So it is suggested that S1 steel can be treated under cryotreatment I condition.

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Table 1 Actual composition of Tool Steels

S.No.	Material	C %	Mn %	Si %	W %	Mo %	Cr %	V %	Other %
1	S1	0.5	---	---	2.5	---	1.5	---	---

Table 2 Hardness in HRC

Material	Before Heat Treatment	After Hardening	After Tempering	-40°C Cold Treatment	-40°C Tempering	-80°C Cold Treatment	-80°C Tempering	-150°C Cryo Treatment	-150°C Tempering	-190°C Cryo Treatment	-190°C Tempering
S1	22	59	57	59	58	59	58	59	58	59	58

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Table 3 Evaluation of Wear resistance and specific-wear resistance at different temperature in S1

Loa d N	Speed rpm	Linear Velocity m/min	Distance Travelled m	WEIGHT LOSS (gm)					SPECIFIC WEAR (gm / m) / 10 000				
				S1-Normal	S1-C1	S1-C2	S1-CR1	S1-CR 2	S1-Nor mal	S1-C1	S1-C2	S1-CR1	S1-CR2
			68.85	0.03	0.03	0.02	0.02	0.01	4.357	4.357	2.905	2.905	1.452
			137.7	0.04	0.03	0.03	0.02	0.02	2.905	2.179	2.179	1.452	1.452
			206.55	0.06	0.05	0.04	0.03	0.03	2.905	2.421	1.937	1.452	1.452
	130	13.77							3.389	2.986	2.340	1.936	1.452
			105.95	0.04	0.03	0.03	0.02	0.02	3.775	2.832	2.832	1.888	1.888
			211.9	0.07	0.05	0.04	0.03	0.03	3.303	2.36	1.888	1.416	1.416
			317.85	0.09	0.07	0.05	0.04	0.05	2.832	2.202	1.573	1.258	1.573
	200	21.19							3.303	2.465	2.098	1.521	1.626
			148.3	0.04	0.04	0.03	0.02	0.02	2.697	2.697	2.023	1.349	1.349
			296.6	0.07	0.06	0.05	0.03	0.03	2.36	2.023	1.686	1.011	1.011
			444.9	0.1	0.08	0.07	0.04	0.04	2.248	1.798	1.573	0.899	0.899
20	280	29.66							2.435	2.173	1.761	1.086	1.086
			69.35	0.04	0.03	0.03	0.02	0.03	5.767	4.326	4.326	2.884	4.326
			138.7	0.05	0.05	0.04	0.03	0.03	3.605	3.605	2.884	2.163	2.163
			208.05	0.07	0.07	0.05	0.03	0.04	3.365	3.365	2.403	1.442	1.923
	130	13.87							4.246	4.624	3.204	2.163	2.804
			106.7	0.04	0.04	0.03	0.03	0.03	3.749	3.749	2.812	2.812	2.812
			213.4	0.06	0.06	0.04	0.03	0.04	2.812	2.812	1.874	1.406	1.874
			320.1	0.08	0.08	0.06	0.04	0.05	2.499	2.499	1.874	1.25	1.562
	200	21.34							3.020	3.020	2.187	1.823	2.083
			149.4	0.06	0.06	0.05	0.04	0.04	4.016	4.016	3.347	2.677	2.677
			298.8	0.08	0.08	0.06	0.04	0.05	2.677	2.677	2.008	1.339	1.673
			448.2	0.11	0.1	0.08	0.05	0.06	2.454	2.231	1.785	1.116	1.339
30	280	29.88							3.049	2.975	2.380	1.711	1.896
			42.8	0.04	0.04	0.03	0.02	0.02	9.346	9.346	7.009	4.673	4.673
			85.6	0.05	0.05	0.04	0.03	0.02	5.841	5.841	4.673	3.505	2.336
			128.4	0.06	0.06	0.05	0.03	0.03	4.673	4.673	3.894	2.336	2.336
	130	8.56							6.620	6.620	5.192	3.505	3.115
			65.85	0.05	0.05	0.03	0.02	0.02	7.593	7.593	4.556	3.037	3.037
			131.7	0.07	0.06	0.05	0.03	0.03	5.315	4.556	3.797	2.278	2.278
			197.55	0.08	0.07	0.06	0.04	0.04	4.05	3.543	3.037	2.025	2.025
	200	13.17							5.653	5.231	3.797	2.447	2.447
			92.2	0.06	0.05	0.04	0.03	0.03	6.508	5.423	4.338	3.254	3.254
			184.4	0.08	0.07	0.06	0.04	0.04	4.338	3.796	3.254	2.169	2.169
			276.6	0.1	0.09	0.08	0.05	0.04	3.615	3.254	2.892	1.808	1.446
50	280	18.44							4.820	4.158	3.495	2.410	2.290

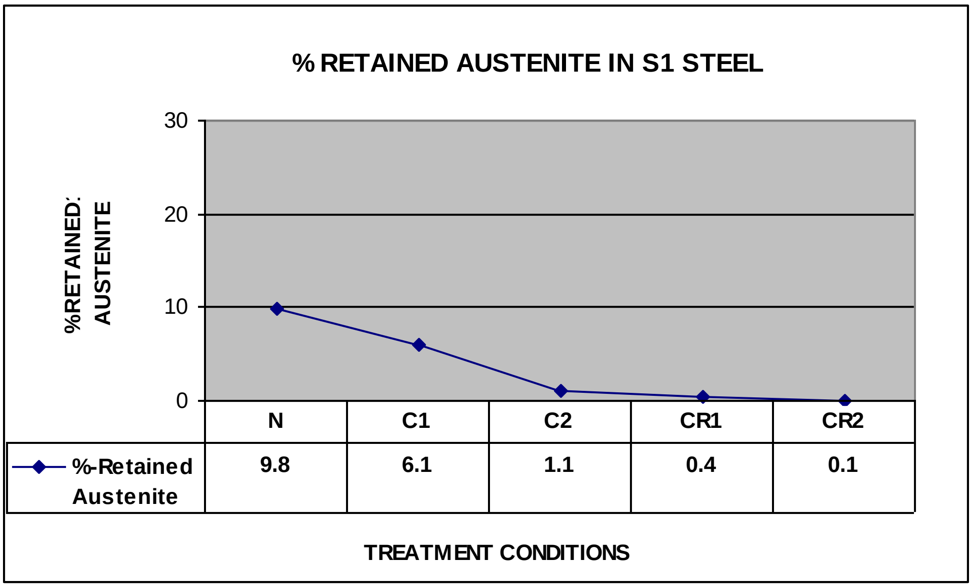


Fig. 6 Variation of %Retained Austenite with Treatment conditions in S1 Steel

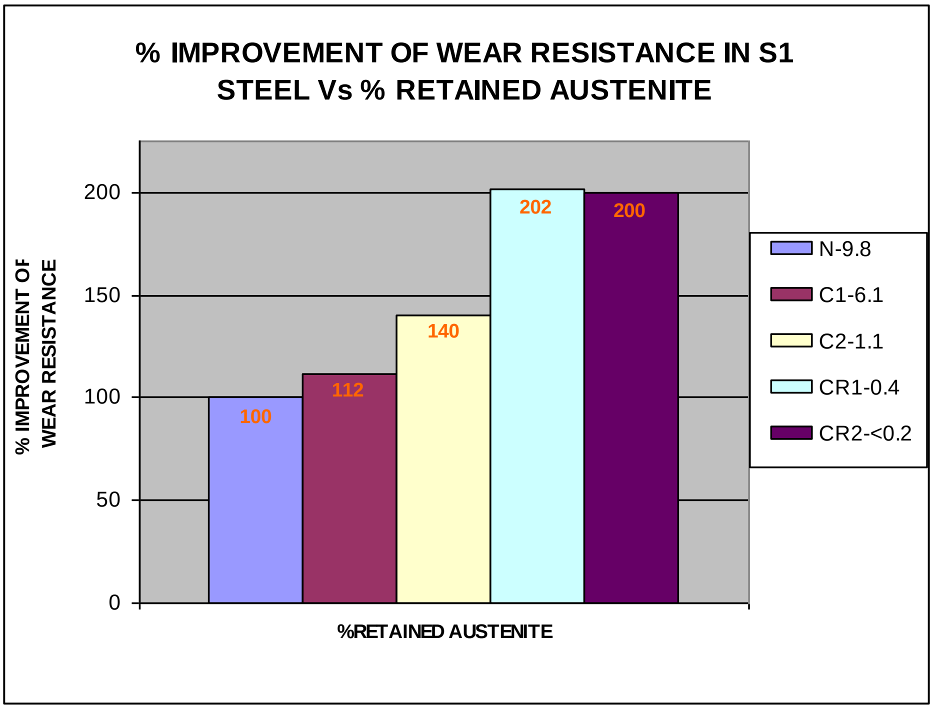


Fig. 7 %-Improvement of Wear Resistance against %Retained Austenite in S1 Steel

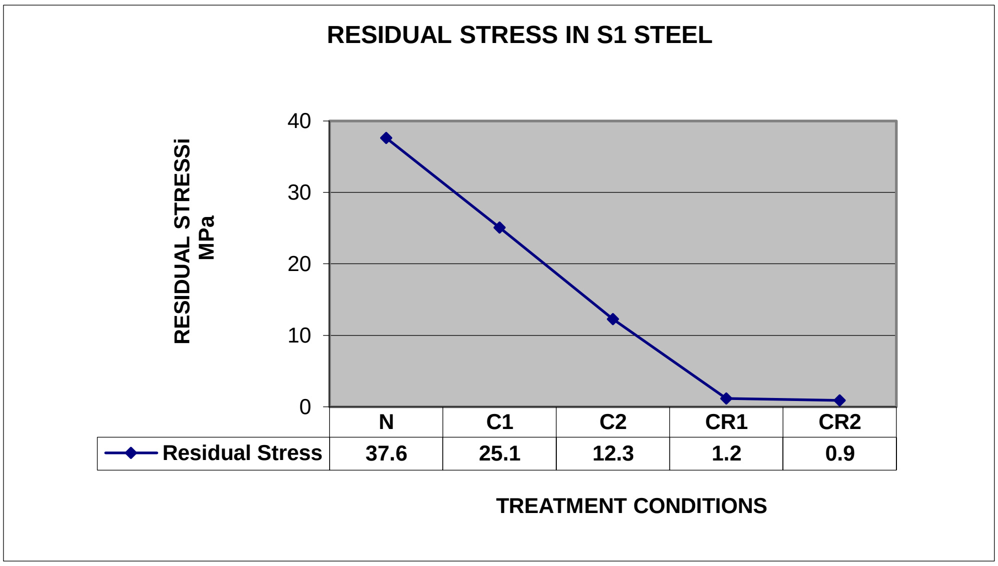


Fig. 8 Variation of Residual stress with Treatment conditions in S1 Steel

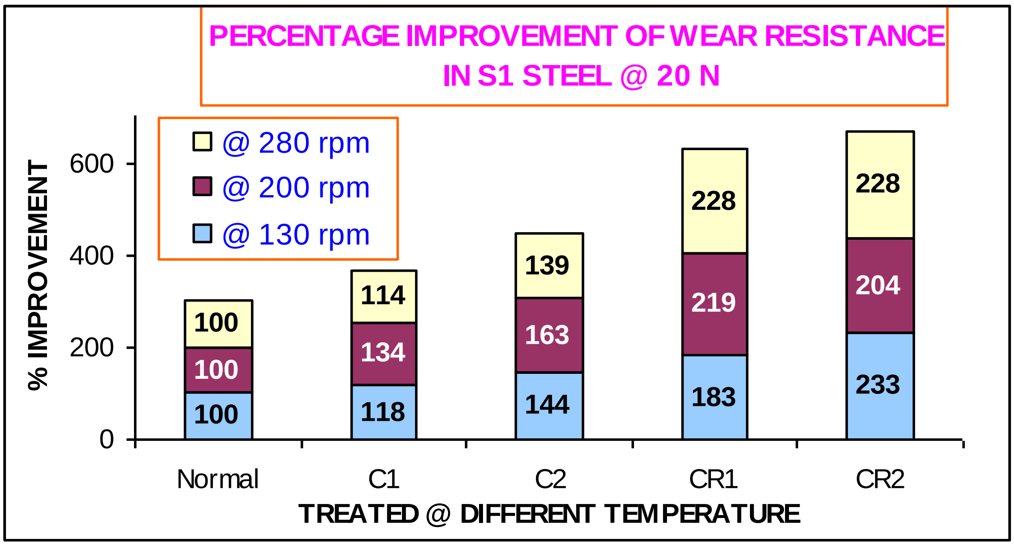


Fig. 9 Percentage Improvement of Wear – Resistance in S1 at 20 N

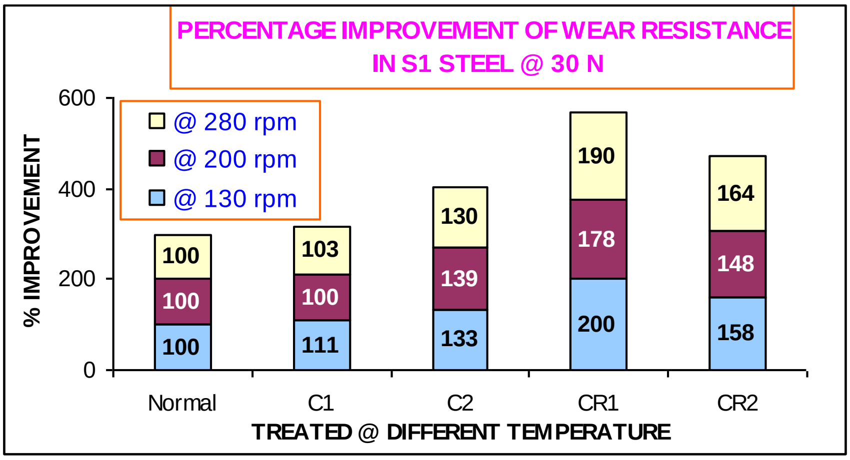


Fig. 10 Percentage Improvement of Wear – Resistance in S1 at 30 N

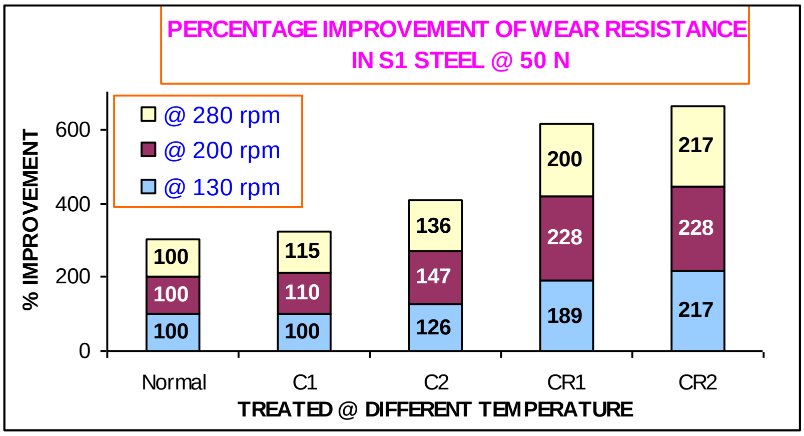


Fig. 11 Percentage Improvement of Wear – Resistance in S1 at 50 N

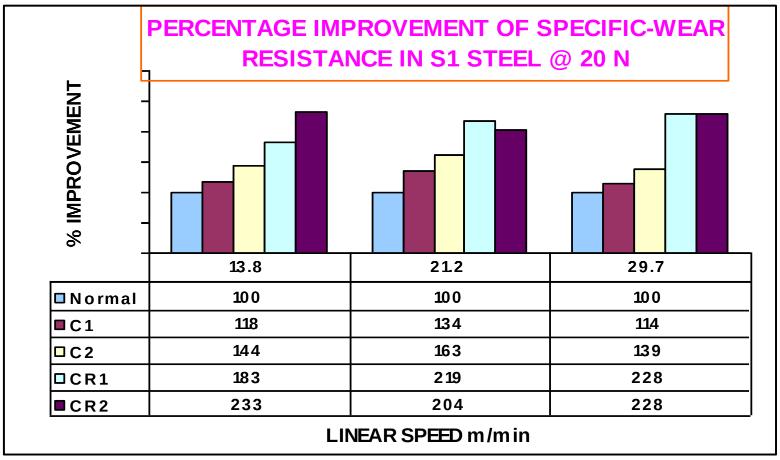
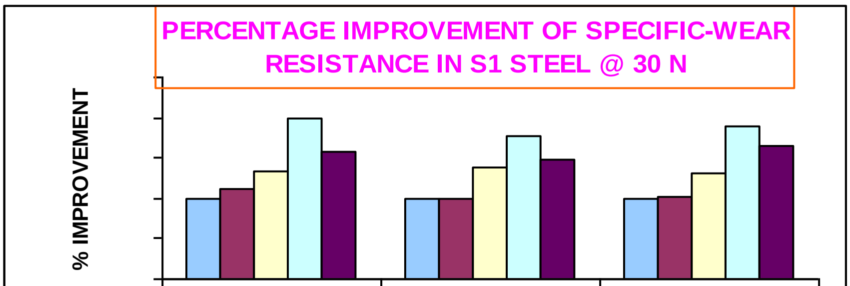


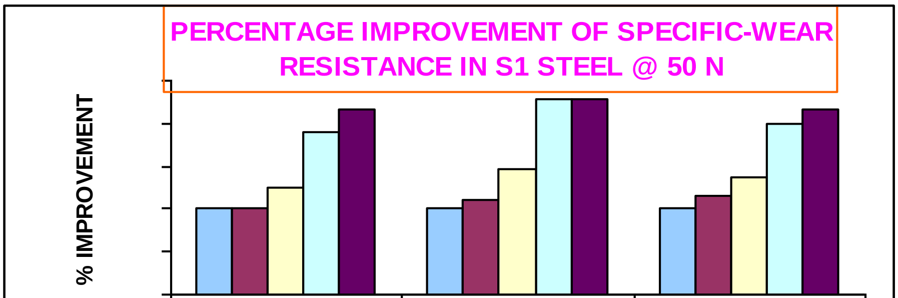
Fig. 12 Percentage Improvement of Specific-wear Resistance in S1at 20 N



	13.9	21.3	29.9
Normal	100	100	100
C1	111	100	103
C2	133	139	130
CR1	200	178	190
CR2	158	148	164

LINEAR SPEED m/min

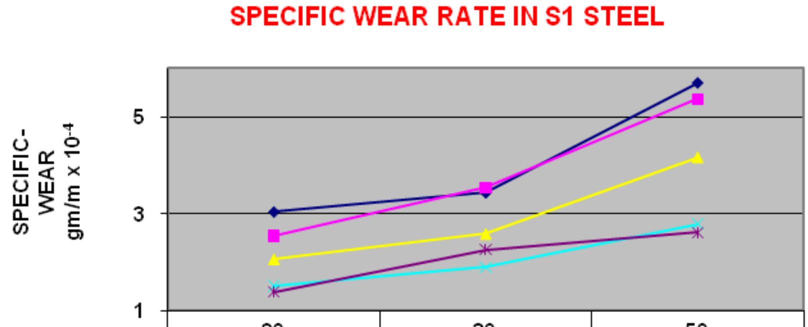
Fig. 13 Percentage Improvement of Specific-wear Resistance in S1at 30



	8.56	13.2	18.4
Normal	100	100	100
C1	100	110	115
C2	126	147	136
CR1	189	228	200
CR2	217	228	217

LINEAR SPEED m/min

Fig. 14 Percentage Improvement of Specific-wear Resistance in S1at 50 N



	20	30	50
NORMAL	3.042	3.438	5.698
C1	2.541	3.54	5.366
C2	2.066	2.59	4.161
CR1	1.514	1.899	2.787
CR2	1.388	2.261	2.617

LOAD (N)

Fig. 15 Specific wear rates with different load in S1 steel