VOL. 11, NO. 2, JANUARY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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EFFECT OF HEAT TREATMENT ON THE FATIGUE BEHAVIOR OF EN8 STEEL

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ABSTRACT

Rotary elements exhibit the fatigue failure due to the insufficiency of fatigue strength. EN8 steel was investigated through various heat treatment processes for its fatigue behavior as it finds core application on the production of transmission shafts, crankshafts and gear. Nitriding was influenced to base metal specimens at the temperature of 5600C in cyanide salt bath. The specimens undergone with induction hardening experienced the electrical input of 32kW at 1800C. As combined heat treatment exhibits better output in fatigue strength, the nitrided specimens were introduced induction hardening with 80 KHz frequency. Hardness test and tensile test were carried out. Rotary Fatigue testing was done in Cantilever type Fatigue testing Machine. Results indicate that improved fatigue strength was attainable by the combined heat treatment process of Nitriding followed by Induction hardening. Fracture study was done using SEM.

Keywords: nitriding, induction hardening, tensile, fatigue, SEM and microhardness.

INTRODUCTION

Even though the field of Automobile has evolved furthermore, the unavoidable phenomenon that plays yet major role in rotating elements subjected to variable or constant loading is Fatigue.

A structural component can influence the Fatigue resistance through the effects of environmental, metallurgical and mechanical variables [1]. The major role of reduction in Fatigue limit is experienced by the defects on surface and subsurface of high strength steels [2]. The fabrication of crankshaft in Automobile industry is mostly utilizing the steel EN8 for good strength and toughness. Fatigue failure is the major threat to the components undergoing repeated loads [3]. Surface treatments on machine elements can improvise the fatigue behaviors.

Nitriding results in Very Low Distortion, Reduced Grinding and Finishing, Temper Resistance, High Operating Temperature. Induction heating implies the effect of Optimized consistency, Improved product quality, Extended fixture failure and environmentally sound.

The fatigue strength is improved approximately 50% with heaviest case depths and 12% of fatigue strength can be improved with respect to liquid nitriding specimens [3]. Nitrides samples exhibit excellent resistance on scuffing and while comparing with the base metals, the nitride specimens provide the fine wear resistance and improve the life of the material [4]. The plasma nitriding treatment enhances fatigue strength and fatigue life of the material with presence of compound layer upto 10µm [5].

The fatigue strength of AISI 4340 steel was increased by up to 91% by ion nitriding process [6]. The residual stress induced induction heating in the stainless steel specimens increases the high cycle fatigue lives [7]. Fatigue strength of hybrid surface modification process combining nitriding and induction hardening specimens was much higher than that of substrate and nitride specimens [8]. The heat treatment process such as nitriding and induction hardening has selected then experimentally conducted few mechanical tests. The result shows fatigue strength of heat treatment had increased [9]. Mostly nitriding improves all mechanical properties and also it has special characterized in fatigue strength. Microhardness was improved due to the internal stress and chemical properties modification in the zone of nitriding. Corrosion and wear also increased by nitriding process [10].

METHODOLOGY

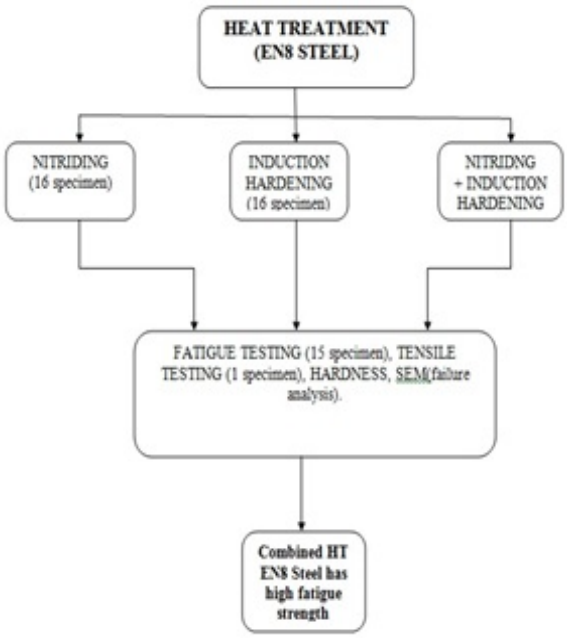

Figure-1. Methodology flow chart.

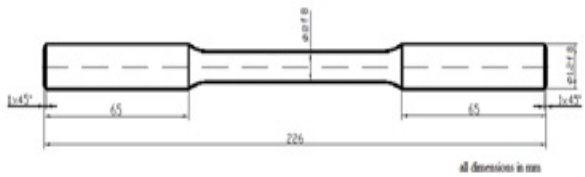

Figure-2. Specimen specification.

The material is EN8 steel and its chemical composition is shown in the table. The initial EN8 steel rod of 16mm diameter is machined as per as specifications as given in the diagram. The specimens are then surface finished for surface roughness and progressed for heat treatment. For the fatigue testing machine specifications the specimens are machined in CNC.

Table-1. EN8 chemical composition.

Element	Content (range)	Content (actual)
Carbon	0.35%-0.45%	0.45%
Manganese	0.60%-1.00%	0.86%
Silicon	0.05%-0.35%	0.24%
Sulphur	0.060%	0.032%
Phosphorous	0.060%	0.014%

Table-2. EN8 mechanical properties.

Tensile strength	780 - 850 Mpa
Yield Strength	465 Mpa
Hardness	201-255 BHN

Table-3. Specimens for respective surface treatment.

Surface Treatment	Number of Specimens
Base metal	16
Nitriding specimen	16
Induction hardening	16
Nitriding and Induction hardening (combined)	16

Out of 16 specimens heat treated 15 specimens were used for fatigue testing and remaining one specimen in each group was subjected to tensile testing.

Nitriding

Nitriding process has an advantage over carburizing such as higher hardness higher compressive residual stresses & also improved wear and corrosion resistance. Mechanical properties of metals are improved by heat treatment processes.

Nitriding process would induce compressive residual stress and also it reduces the tensile residual stress which leads to increase in fatigue as well all the mechanical properties.

In nitriding processes of steel have a 400 MPa compressive residual stress, which increase 35% of fatigue strength [11]. There was 50% improvement in the fatigue life for the specimen subjected to ion nitriding [12]. The specimens here subjected to liquid nitriding in particular salt bath nitriding. The salt bath is heated to 560o C. Nitrogen in the salt bath diffusing on the surface of the specimen. At that temperature the nitrogen from the salt diffuses in the specimen surface. By increasing the time period nitrogen diffusion rate on case depth varies.

Figure-3. Nitrided specimens.

Induction Hardening

Table-4. Induction hardening specification.

Induction hardening	Specifications
Power	32 KW
Speed	Major ϕ: 1900 mm/min
	Minor Φ: 2300 mm/min
Dwell	0.2 seconds
Frequency	80 KHz
Coil ID	17 mm

Through induction hardening process the tensile residual stress in the core would induce and the compressive residual stress will increase on the surface, it leads to increase of fatigue strength as well as wear strength [13].

By induction hardening process increased surface hardness upto 600 HV and the compressive residual stress induced along the longitude direction of 500Mpa which also increase of fatigue strength [14]. Hence hybrid heat treatment shows the better result for

VOL. 11, NO. 2, JANUARY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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fatigue life, some nitrided specimens subjected to induction hardening.

Combined Nitriding and Induction Hardening

Nitriding was carried out then the specimen was subjected to induction hardening process, Figure-5. Show the combined processed fatigue testing specimens.

Figure-4. Combined nitriding and induction hardened specimens.

EXPERIMENTATIONAL TEST

The rotating bending fatigue test was carried out in FTG (cantilever type). After clamping one end of the specimen in the load cell and the other end was fitted on the collect which is connected to motor.

Load was applied on the load cell mechanically and the corresponding number of cycle was noted from counter from the obtained data S-N curve was plotted.

To calculate the bending stress,

P = load applied over the specimen

L = 130 cm,

Bending moment (Mb) = PL

Bending stress (fb) = Mb/Z kg/cm2

Where, Z = section modulus = Πd3/32.

RESULTS AND DISCUSSION

Micro Hardness

Chemical modification on the surface takes place due to the Nitriding and induction hardening process. It increases micro hardness in the diffused surface. While increasing the case depth, the micro hardness reduces.

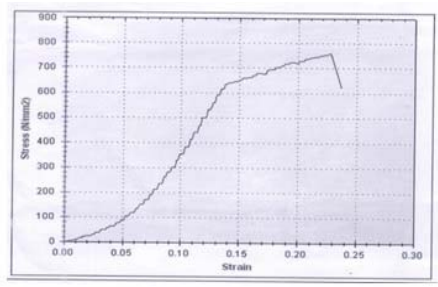
Table-5. Heat treatment and hardness.

S.No.	Specimen	Average Hardness (Hv)
1.	Nitriding	550
2.	Induction Hardening	525
3.	Combined	620

From the Micro Hardness result, it is seen that the specimens nitrided and induction hardening have shown higher hardness value than the remaining two types of heat treatment.

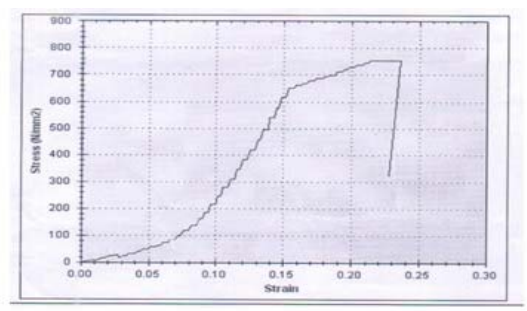
Tensile Strength

Tensile strength increases when hardness increases. Graph-1 and 2 shows Tensile test results carried out using UTM machine.



Input Data			Output Data		
Specimen Shape	: Solid Round		Load At Yield	: 31.7	kN
SpecimenType	: Steel		Yield Stress	: 615.176	N/mm2
Specimen Description	: Specification: Nitriding Process Specimen		Load at Peak	: 39.020	kN
			Tensile Strength	: 757.230	N/mm2
Speciman Diameter	: 8.1	mm	Reduction Area	: 7.27	%
Initial Gauge Length	: 36	mm	Elongation	: 5.56	%
Final Sp Diameter	: 7.8	mm			
Final Gauge Length	: 38	mm			
Final Area	: 47.78	mm2			
Specimen C S Area	: 51.53	mm2			

Graph-1. UTM result of nitrided base metal.



Input Data			Output Data		
Specimen Shape	: Solid Round		Load At Yield	: 32.72	kN
SpecimenType	: Steel		Yield Stress	: 650.944	N/mm2
Specimen Description	: Specification: Nitriding Process Specimen		Load at Peak	: 37.840	kN
			Tensile Strength	: 752.804	N/mm2
Speciman Diameter	: 8	mm	Reduction Area	: 2.48	%
Initial Gauge Length	: 36	mm	Elongation	: 4.44	%
Final Sp Diameter	: 7.9	mm			
Final Gauge Length	: 37.6	mm			
Final Area	: 49.02	mm2			
Specimen C S Area	: 50.27	mm2			

Graph-2. UTM Result of combined heat treatment.

Table-6. Tensile testing result of heat treated specimens.

Process	Yield strength (N/mm2)	Tensile strength (N/mm2)
Nitriding	615.1766	757.23
Induction hardening	607.026	737.047
Combined	650.944	752.80

VOL. 11, NO. 2, JANUARY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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Fatigue Test

The fatigue life increases for increasing tensile strength. The S-N curve was plotted for the different heat treated specimens.

Figure-5. Fatigue testing.

Table-7. S-N detail for nitrided specimens.

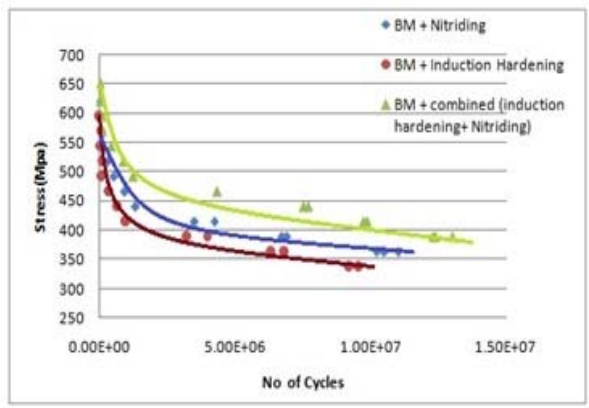
Specimen No.	Nitrided Base metal	
	Stress (MPa)	*No. of cycles*
1.	620.7	2.32E+04
2.	594.84	4.25E+04
3.	568.98	7.50E+04
4.	543.12	9.21E+04
5.	517.252	2.87E+05
6.	491.39	5.34E+05
7.	465.53	9.25E+05
8.	439.66	1.32E+06
9.	413.79	4.23E+06
10.	413.79	3.50E+06
11.	387.93	6.91E+06
12.	387.93	6.72E+06
13.	362.08	1.02E+07
14.	362.08	1.10E+07
15.	362.08	1.05E+07

Table-8. S-N detail for induction hardening specimens.

Specimen No.	Induction Hardening	
	Stress (MPa)	*No. of cycles*
1.	594.84	1.02E+04
2.	568.98	2.36E+04
3.	543.12	5.45E+04
4.	517.252	6.98E+04
5.	491.39	9.54E+04
6.	465.53	3.54E+05
7.	439.66	6.72E+05
8.	413.79	9.71E+05
9.	413.79	9.82E+05
10.	387.93	3.23E+06
11.	387.93	3.96E+06
12.	362.08	6.82E+06
13.	362.08	6.32E+06
14.	336.21	9.20E+06
15.	336.21	9.56E+06

Table-9. S-N detail for combined nitriding and induction hardening specimens.

Specimen No.	Combined (Nitriding + Induction Hardening)	
	Stress (MPa)	*No. of cycles*
1.	650	3.25E+04
2.	620	6.25E+04
3.	594.84	9.21E+04
4.	568.98	1.07E+05
5.	543.12	4.35E+05
6.	517.252	8.92E+05
7.	491.39	1.24E+06
8.	465.53	4.34E+06
9.	439.66	7.54E+06
10.	439.66	7.72E+06
11.	413.79	9.75E+06
12.	413.79	9.86E+06
13.	387.93	1.23E+07
14.	387.93	1.24E+07
15.	387.93	1.30E+07



Graph-3. S-N curve for combined nitriding and induction hardening specimens.

Table-10. Endurance limit for surface treated specimens.

Specimen	Endurance limit (N/mm^2)	Fatigue life (N) cycles
Nitriding	362.08	1.05E+07
Induction hardening	336.01	9.56E+06
Combined	387.93	1.30E+07

From the Fatigue data obtained through fatigue testing, it is clearly seen that the combined nitriding and induction hardening process shows higher endurance limit and fatigue life.

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SEM analysis

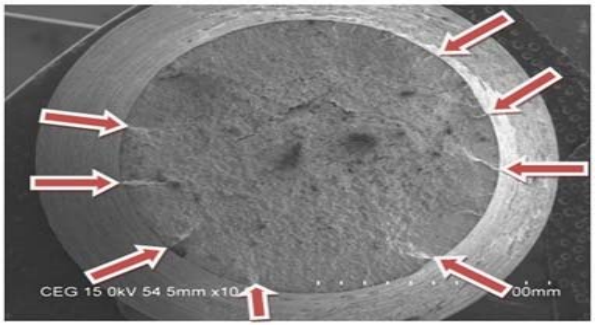

Figure-6. Crack nucleation was more on the outer surface and propagated to core in EN8 steel.

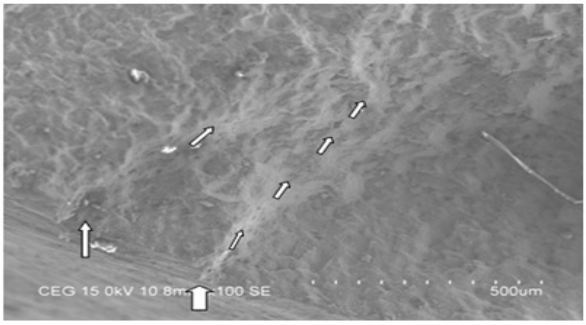

Figure-7. Crack propagation in the base metal.

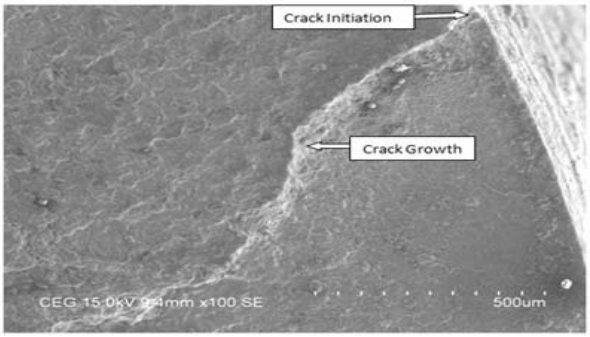

Figure-8. SEM image of base metal specimens.

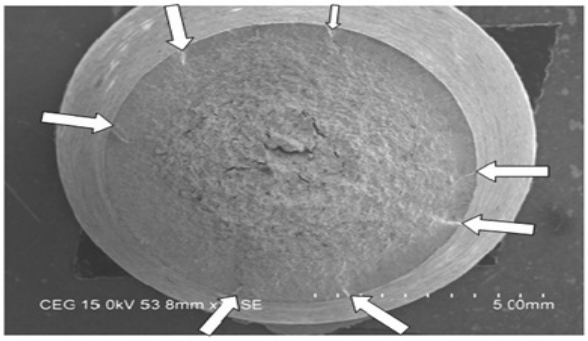

Figure-9. Brittle fracture occurs on the surface of specimen up to the nitride case depth and the remaining portion undergone ductile fracture.

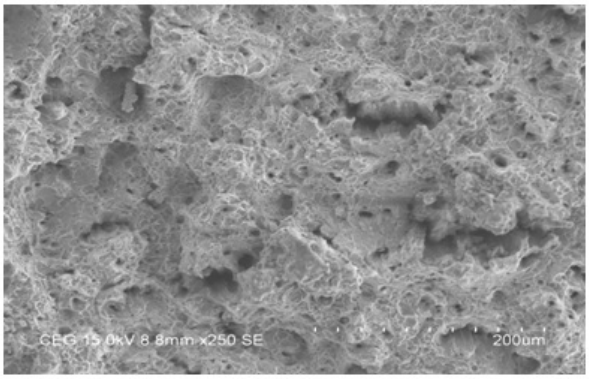

Figure-10. Ductile fracture in the core of specimen.

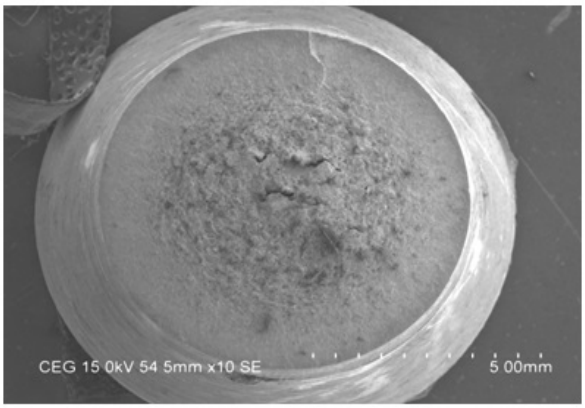

Figure-11. SEM image of nitrided specimens.

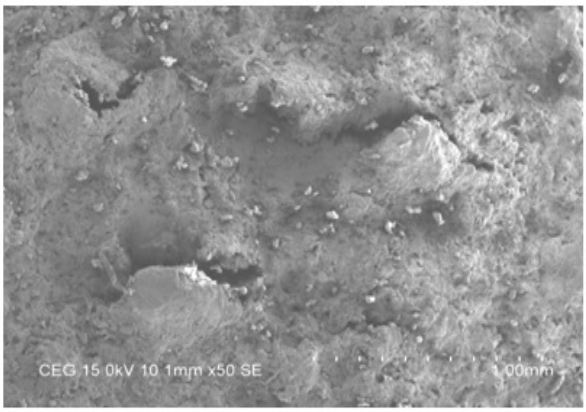

Figure-12. SEM image of induction hardening and nitriding (combined) process.

Two different kinds of fractures region can be observed, one is the ductile zone which occurs in the centre and the brittle fracture can be observed in the edge of a brittle layer.

CONCLUSIONS

- Nitriding(550Hv) and induction hardening process(525Hv) increase micro hardness in the diffused surface. Combined Nitriding and induction hardening process gives 620Hv of Hardness.
- Tensile strength increases when hardness increases. Tensile strength of Nitrided Specimen is 757.23 N/mm2, Induction Hardened specimen is 737.047 N/mm2 and Combined Nitrided and Induction Hardened specimen is 752.80 N/mm2.
- The fatigue life increases for increasing tensile strength. The endurance limit of combined heat treatment showed higher than remaining individual treatment.

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