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EFFECT OF CRYOGENIC TREATMENT ON EN8 STEEL USED FOR PRESS TOOL

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ABSTRACT

Cryogenic Treatment is an additional process to conventional heat treatment in material processing technology. Not like coatings of superior materials over other metals, it is a onetime process that affects the entire section of the component. Cryogenic treatments are considered to be a good way to reduce the retained austenite content and increase the performance of tools. In this study cryogenic treatment is applied on EN8 steel which is used as a press tool, subsequently determining its properties by means of hardness test and microscopic observation. Furthermore, optimization of tools (normal and cryogenic), pressure and stroke length has been done using Response Surface Methodology (RSM) based desirability function for the minimization of surface roughness and maximization of stamping depth. Pneumatic powered normal and cryogenic EN8 tools are observed under specific operating conditions. Obtained hardness values of EN8 before and after cryogenic treatment are 223 BHN and 310 BHN respectively. Also retained martensite structure is obtained which improves its surface properties. Furthermore, a fatigue life analysis has been carried out to examine the effect of cryogenic treatment on the life cycle of the same tools. Fatigue analysis proved that life cycle has been improved tremendously after cryogenic treatment.

INTRODUCTION

All Metals may not possess desired properties in their final product. Alloying and Heat treatments are two methods which are widely used to control material properties. Heat treatment is the controlled heating and cooling operations performed on the material. It is an operation or combination of operations which include heating at a specific rate, soaking at a temperature for some specific time and cooling at some specified rate. The aim of it is to obtain the desired microstructure to achieve some desired properties like physical, mechanical, magnetic & electrical properties. When the material is subjected to heat treatment the atomic structure may change due to movement of dislocations, increases or decrease in solubility of atoms, increase in grain size, formation of new grains, formation of new different phase and change in crystal structure etc. Objectives of Heat Treatments are to increase strength and hardness, to increase wear resistance, to obtain fine grain size, to increase ductility and toughness, to improve machinability, to improve cutting properties of tool, to improve surface properties etc.

Word Cryogenic is made of two Greek words: (1) Kryo: Which means Very cold (frost) and (2) Genics: Which means to produce. This is a technology where everything we process gets frozen at ultra-low temperatures of -193°C. Then everything is held down at temperatures around of -193 °C for 12-48 hours followed by gradual ascend and tempering. This process consists of controlled cooling of conventionally hardened materials to a specified temperature followed by controlled heating of the materials back to the ambient temperature for subsequent tempering process.

The cryogenic treatment can be classified into three different temperature regimes: Cold Treatment (CT, ≥193 K or -80 °C), Shallow Cryogenic Treatment (SCT, 193–113 K or -80 °C to -160 °C), Deep Cryogenic Treatment (DCT, 113–77 K or -160 °C to -196 °C).Two different types of cryogenic solutions used for the treatment of materials: Liquid Nitrogen (-196 °C)and Liquid Helium (-269 °C). Liquid nitrogen is a cryogenic liquid. At atmospheric pressure, it boils at −196 °C. When insulated in special containers called Dewar flasks, it can also be transported. Liquid nitrogen is generally used as it is cheaper than liquid helium and can be available easily.

There is no clear understanding of the mechanisms by which cryogenic treatment improves the performance of metals. Most researchers believe that the martensite temperature is below 0 °C due to the higher alloying element in alloyed metals. It means that at the end of the heat treatment, a low percentage of austenite will be retained at

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room temperature. The retained austenite, as a soft phase in metals, can reduce the product life. Deep cryogenic treatment is used to transform this retained austenite into martensite. As a result, the retained austenite level is reduced and the good working life is obtained. Cryogenic treatment also facilitates the formation of finer secondary carbides in the martensite, thus improving the wear resistance.

Many studies have focused on improving the properties of metals by deep cryogenic treatment. Positive effects have been noticed in tool steels, carburized steels, cast irons and other materials, as discussed in a detailed literature review. However, the mechanisms behind this treatment remain unclear, making it difficult to predict the effects of this treatment on a particular alloy. Thus, specific experimental testing is required for each material to be treated.

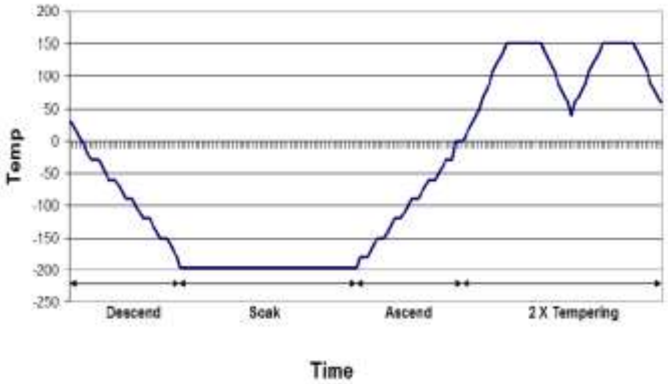


Figure 1. Deep cryogenic treatment Cycle

The accepted temperature for cryogenic or sub-zero treatment has been 193K where dry ice can be used for cooling. But, the results of few recent studies suggest that the temperature of cryogenic treatment should be less than 193K in order to obtain the maximum improvement in mechanical properties of metals. The lowest temperature of cryogenic treatments may be 77 K, which is the boiling temperature of liquid nitrogen at normal atmospheric pressure. This is why deep cryogenic treatment is said to be superior to Cold and Shallow treatments as in deep cryogenic treatment temperature 113 K to 77 K is used (-160 °C to -196 °C).

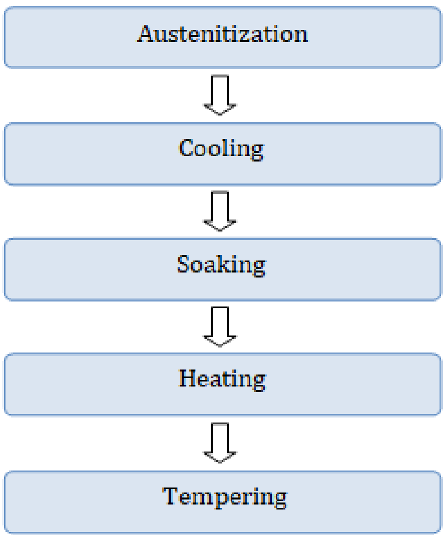


Figure 2. Process of cryogenic heat treatment

Cryogenic process consist of total five stages. First stage is austenitization in which heating from room temperature to its austenitizing temperature (around 1100 °C) at an extremely slow rate ranging from 0.5 to

1.5°C/min is performed. Second stage is cooling. In this stage direct cooling from austenitizing temperature to -196 °C at the rate of 1.5 to 2 °C/min is carried out. It is also called as quenching. Third stage is soaking in which for a period of time ranging from 24 to 36 hours depends upon the material, the material is kept for soaking at this temperature. Fourth stage is heating in this heating from -196 °C to room temperature at the rate of 0.5 to 1°C /min is performed. And the last stage is tempering in which reheating of the metal at predetermined temperatures which are lower than the transformational temperature (around 150 °C) to obtain different combinations of mechanical properties in the material is carried out.

LITERATURE SURVEY

K Prudhvi & Mrs. Venkata Vara Lakshmi: They studied about the normal high-speed steel tool for machining. But it is difficult to machine the hardened materials. So they apply cryogenic treatment to the tool for a certain time. Hardness is tested for the tool before and after treatment. Hardness for the untreated tool was 64.06 HRC and for a treated tool was 65.83 HRC. Therefore hardness is increased by 1.73 HRC than the untreated tool. They have concluded from the experiments that there are 34.17 seconds decreases in machining time & there is no tool wear when machining EN8 and when machining EN 19 there are 22.04 seconds decrease in machining time & 0.03g increase in tool wear resistance. Deep cryogenic treatment has a significant effect on increment in the wear resistance and correspondingly reduces machining time of steels such as EN8 and EN19.

Marcos Perez, Francisco Javier Belzunce: Cryogenic treatment was carried out on H13 tool steel used for hot forging dies, subsequently determining its mechanical properties tensile, hardness and fracture toughness tests. This paper explains the performance of four different heat treatments applied to H13. Two quenching media (gas and oil) and the effects of a cryogenic stage were studied. Oil quenching by cryogenic treatment was carried out as the best one among all four treatments. The mechanical properties of the H13 steel were measured by tensile, hardness and fracture tests. They concluded that cryogenic treatment notably improves the fracture toughness of H13 steel. Cryogenic with gas and oil quenching generates 22.5% and 24% respectively increase in toughness when compared to without cryogenic. So quenching medium also affects its toughness. Deep cryogenic treatments reduce the retained austenite content in H13 steel.

D. Das, K. K. Ray, A. K. Dutta: Their study examined the effect of the temperature of the treatment on the wear behavior of AISI D2 steel. Samples were subjected to conventional treatment (CONT), Cold Treatment (CT), Shallow Cryogenic Treatment (SCT) and Deep Cryogenic Processing (DCT) in separate batches. CONT consists of hardening and tempering; while in CT, SCT and DCT, an additional step of controlled sub-zero treatment with the lowest quenching temperature under 198, 148 and 77 K respectively, was incorporated into the curing and quenching treatments. Microstructural examinations were performed using optics and SEM. The hardness was measured by a Vickers hardness tester. They concluded that all types of sub-zero treatments appreciably improve the wear resistance of the die steels compared to the CONT ones. Improvement in wear resistance by SCT and DCT is significantly higher than that achieved by CT, and the maximum improvement is obtained by DCT. The obtained hardness of AISI D2 steel for CONT and DCT are 759 and 791 VHN, respectively and typical values of their specific wear rate are 1.03×10^{-6} and 8.26×10^{-9}mm3 $N^{-1}mm^{-1}$.The obtained results lead to the conclusion that lower the temperature of sub-zero treatment higher is the improvement in wear resistance.

A Joseph Vimal, A Bensely, D. Mohanlal: They studied the behavior of Deep Cryogenic Treatment (DCT) on EN31 steel sample work piece used for bearing to improve its wear resistance. The austenitizing temperature in this study is 1039 K (819 °C) after that quenching was done at 40 °C and tempering at 140 °C. They observed wear resistance by pin-on-disc test, microstructure by SEM and hardness test by VHN. They came to conclude that DCT gives rise to hardness with or without tempering. Also, the stated that wear resistance increases as hardness increases. It was observed that by cryogenic treatment, wear can be decreased by a maximum of 75% depending on the service conditions.

A. Akhbarizadeh , A. Shafyei, M. A. Golozar: They studied the effects of cryogenic treatment on the wear behavior of D6 tool steel. For this, two temperatures were used: -63 °C as SCT and -185 °C as DCT. The effects of cryogenic temperature (Shallow and Deep), cryogenic time and stabilization temperature on the wear behavior of D6 tool steel were studied. Hardness and wear test were carried out. Results showed that the cryogenic treatment increases hardness. The samples which were cryogenically treated for a longer time or deep cryogenically treated showed further increase in hardness. The Higher hardness of the shallow cryogenically treated samples was due to the decrease of the retained austenite. It was observed that the cryogenically treated samples have higher wear resistance compared with the conventionally heat-treated samples; this improvement was 5–11% in SCT and 39–68% in the DCT samples.

V. Firouzdor, E. Nejati, F. Khomamizadeh: The effect of deep cryogenic treatment on wear resistance and tool life of M2 HSS drill was studied in their research work. The austenite temperature was 1100 °C and gas quenching was done in nitrogen gas and consequent tempering was done at 600 °C for 2h. Deep cryogenic treatment consisted of slowly cooling drills to approximately −196 °C and holding at this low-temperature for 24h and gradually bringing the specimens back to room temperature. They concluded that Cryogenic treatment profoundly improved the wear resistance of M2 HSS drills in the configuration of high-speed dry drilling of steels. Low-temperature tempering (200 °C) after cryogenic treatment was also found to be highly beneficial. It has been deduced that fine carbide precipitation during cryogenic treatment is the main reason for wear resistance improvement. Transformation of retained austenite to martensite could also contribute to wear resistance improvement, i.e. enhanced hardness value. Cryogenic treatment could not only facilitate the carbide formation and increase the carbide population in martensite matrix, but also make the carbide distribution more homogeneous.

J. Y. Huang, Y.T. Zhu, X. Z. Liao, I. J. Beyerlein: They investigated the reason behind the improvement in hardness and wear resistance after cryogenic treatments. M2 tool steel rod with a diameter of 6.35 mm was used in the experiment. Preheating at815 °C in a vacuum furnace, then continuously heating to austenite temperature of 1100 °C in a nitrogen atmosphere, holding for 1 h, followed by quenching to an ambient temperature in a cool nitrogen gas. The cryogenic treatment was performed by soaking the samples in liquid nitrogen for 1 week. They came to the conclusion that cryogenic treatment cannot only facilitate the carbide formation and increase the carbide population and volume fraction in the martensite matrix, but can also make the carbide distribution more homogeneous. This shows increases in carbide density and volume fraction, which may be responsible for the improvement in wear resistance.

D. Mohanlal, S. Renganarayanan, A. Kalanidhi: Materials considered for this research were M2, T1 and D3 steel used for dies and punches to check the influence of cryogenic treatment with respect to the carbon percentage. Also, the effect of TiN coating on cryo treated tools and cryo treatment on TiN coated tools were illustrated. TiN coating imparts 48.4%, 42% and 41% improvement while cryogenic treatment imparts 110.2%, 86.6% and 48% improvement in Ti, M2 and D2 steels respectively. Cryogenic treatment to TiN coating is superior also and it provides 45% extended tool life then cryo treatment alone. They also concluded that soaking time is more important than lowering the temperature.

EXPERIMENTAL SETUP AND PROCEDURE

Material which has been chosen for this experimental work is EN8 which lies under Mild Steel category. Chemical composition of it is as below.

Table 1. Chemical composition of EN8

Content	C	S	Mn	S	P
Value	0.44%	0.20%	0.76%	0.023%	0.011%

Whole experiment has been conducted at Prinz Automech Pvt. Ltd., MIDC, Pune. Dimensions and design data have been selected as per the standard catalog of Tenroy Toolings Manufacturing Co. Ltd, China. Press tool is pneumatically driven. There is an emboss in tool plate-2 and pattern on tool plate top plate-1. Vertical siding motion is given to the tool plate-1 and embossing pattern is generated on work piece. Here silver sheet of 0.3 mm thickness is used as a work piece as the company in which the entire project has been carried out is making embossing press machines for the precision works over gold and silver sheets. A simple pattern of 25x25x25 mm square have been developed as an embossing pattern on tool plate-1 as it is very easy to measure surface roughness diagonally.

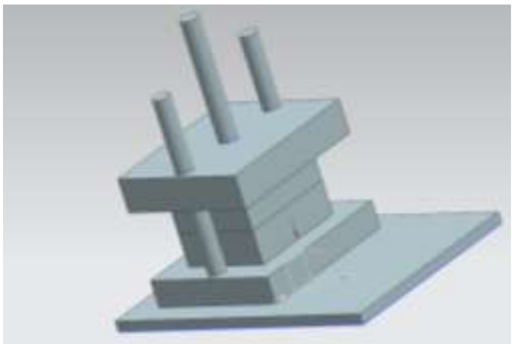
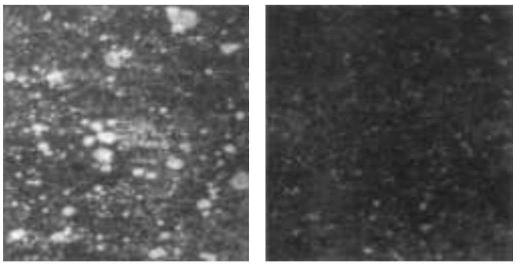


Figure 3. Assembly of setup

Cryogenic treatment of material has been done by "Kryospace", Pune.
The following treatment process has been followed:
1. Descend: From room temp to -193 ºC
2. Soak: At -193 ºC for 22 to 24 hr
3. Ascend: From -193 ºC to room temperature
4. Tempering: 2 times at 150 ºC

As expected, cryogenic treatment has positive effect on the hardness of EN8. Its hardness increases from 223 BHN to 310 BHN. Advanced Surface Microscopy (ASM) result shows that cryogenic treatment converts soft austenite is nearly completely harder, abrasion resistant martensite (99.7%) at lower temperatures. The mechanism by which cryogenic treatments contribute to the enhancement in hardness is mainly through the precipitation of fine secondary carbides and the transformation of retained austenite into martensite.



(a) (b)

Figure 4. Difference in microstructure before (a) and after (b) cryogenic treatment

Input and Output parameters have been selected as per the requirement of the company's products. Pressure, stroke length of tool and tool are selected as input parameters as these affect the output parameters which are stamping depth and surface roughness. The aim is to maximize the stamping depth and minimize surface roughness. After conducting experiments stamping depth was measured by ANY JEW95VC200 150 mm, 6 inch LCD digital vernier caliper and digital depth gauge and surface roughness was measured by Mitutoyo SJ-210 surftest profilometer. Design of Experiment with measured output parameters are as shown in Table-1.

Table 2. DOE with measured output parameters

StdOrder	Pressure(Bar)	Tool	Stroke Length(mm)	Stamping Depth(µm)	Surface Roughness
1	4	Normal	200	0.79	1.270
2	4	Normal	250	0.81	1.275
3	4	Normal	300	0.95	1.263
4	4	Cryogenic	200	0.83	1.206

5	4	Cryogenic	250	0.86	1.242
6	4	Cryogenic	300	1.05	1.113
7	5	Normal	200	1.20	0.800
8	5	Normal	250	1.24	0.895
9	5	Normal	300	1.27	0.763
10	5	Cryogenic	200	1.27	0.421
11	5	Cryogenic	250	1.33	0.671
12	5	Cryogenic	300	1.47	0.526
13	6	Normal	200	1.50	0.389
14	6	Normal	250	1.52	0.263
15	6	Normal	300	1.66	0.313
16	6	Cryogenic	200	1.52	0.326
17	6	Cryogenic	250	1.54	0.373
18	6	Cryogenic	300	1.75	0.365

ANALYSIS

In this research work statistical analysis on minitab-17 for the optimization of output parameters and fatigue analysis for the fatigue life calculation of press tool on ANSYS-16 have been carried out.

Statistical Analysis

During current investigation for the analysis of process parameters, p-value has been used to check the effect of process parameters on the responses. During investigation it is set at 95% confidence level. So if p-value is less than 0.05 then that particular variable is said to have significant effect on responses. According to the ANOVA table for depth indicates that all three factors pressure, tool and stroke length have p-values 0, 0.001 and 0 respectively which are lower than 0.05. So all these have significant effect on response variables. Pressure is the most significant parameter for depth. P-value for pressure is 0 and F-value is 513.38. After pressure, stroke length is found to have significant effect with P=0 and F=35.3. Finally tool has also significant effect on stamping depth.

Table 3. ANOVA table for stamping depth

ANOVA for Depth					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Pressure(Bar)	2	1.4869	0.74345	513.38	0
Tool	1	0.02569	0.025689	17.74	0.001
Stroke Length(mm)	2	0.10223	0.051117	35.3	0
Error	12	0.01738	0.001448		
Total	17	1.6322			
Model Summary					
S	R-sq	R-sq(adj)	R-sq(pred)		
0.0380545	98.94%	98.49%	97.60%		

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It can be seen from ANOVA table that R-sq value is 98.94% which indicates 98.94% of variation in depth for current parameter settings. Larger R-sq value also indicates vary good predictions with current variables. According to main effect plot in figure 5, we can see that as pressure increases from 4 to 5 bar depth also increases linearly. With further increase in pressure from 5 to 6 bar same trend is noticed. Increase in stroke length from 200 to 250 mm slightly changes the depth as it shows rapering effect. But a sudden increase in depth has been observed as it changes from 250 mm to 300 mm. cryogenic condition shows good effect on depth as depth observed with cryogenic condition is more than that of normal tooling condition.

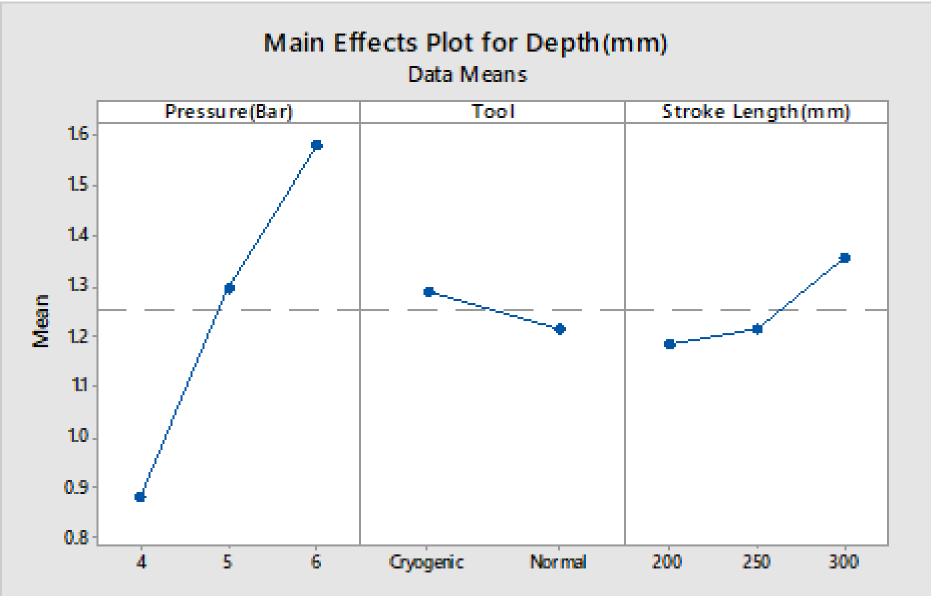

Figure 5. Main effect plot for depth

According to the ANOVA table for surface roughness, it indicates that pressure and tool are the significant factors for surface roughness. Stroke length does not show any significant effect for the same response. With P-value 0.000 and F-value 120.11 pressure is the most significant factor for surface roughness. After it tool shows significant effect on the same response with P=0.039 and F=5.38. Both parameters have significant effect with confidence level 95%.

Table 4. ANOVA table for surface roughness

ANOVA for Depth					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Pressure(Bar)	2	1.4869	0.74345	513.38	0
Tool	1	0.02569	0.025689	17.74	0.001
Stroke Length(mm)	2	0.10223	0.051117	35.3	0
Error	12	0.01738	0.001448		
Total	17	1.6322			
Model Summary					
S	R-sq	R-sq(adj)	R-sq(pred)		
0.0380545	98.94%	98.49%	97.60%		

From the main effect plot, it can be seen that when pressure increases from 4 bar to 5 bar, surface roughness shows a large decrease with linear effect. Subsequently increase in pressure from 5 bar to 6 bar, the same trend has been

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notices as surface roughness decreases. Cryogenic tooling condition shows good surface roughness as for this surface roughness is smaller than that of normal tooling condition.

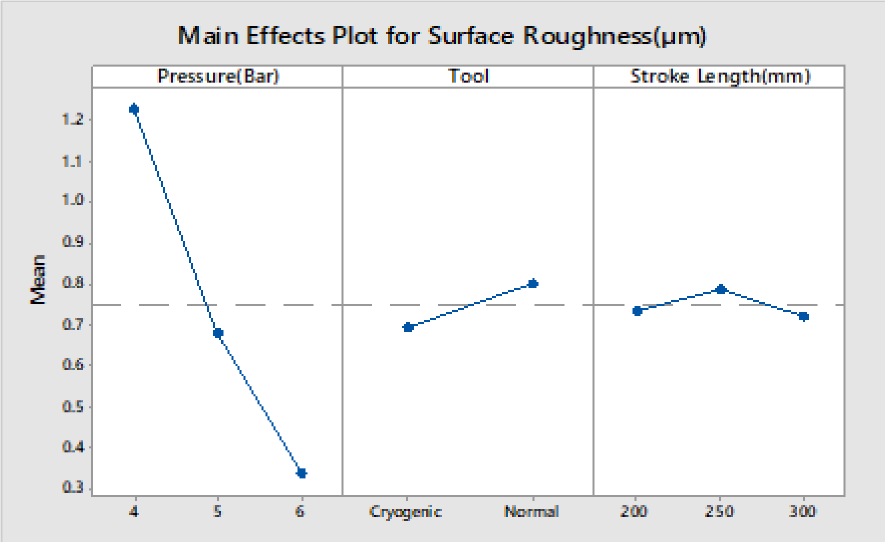


Figure 6. Main effect plot for surface roughness

Contour plot as shown in figure 7 suggest that minimum surface roughness can be obtained at pressure of 6 bar & stroke length range between 200 to 300 mm. So we can say that pressure has maximum influence on surface roughness response. Contour plot as shown in figure 8 suggest that maximum stamping depth can be obtained at stroke length range between 280 to 300 mm & at pressure of 6 bar. So for this response both parameters are said to be effective.

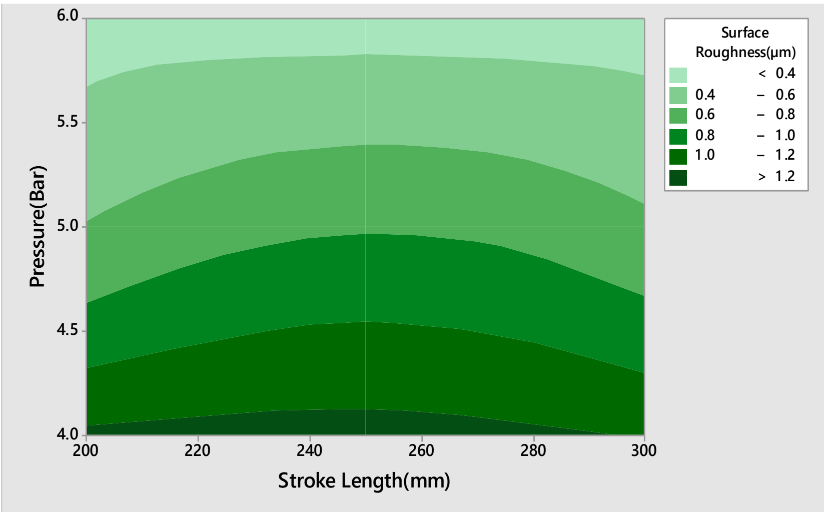


Figure 7. Contour plot of surface roughness v/s pressure, stroke length

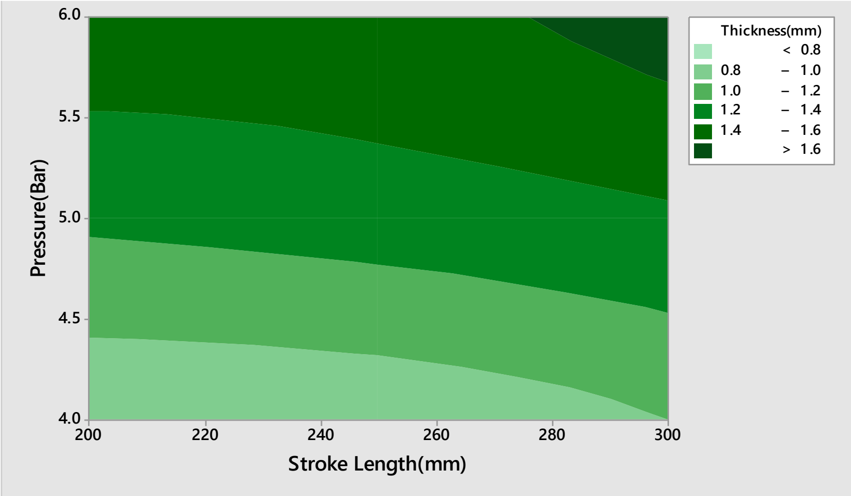


Figure 8. Contour plot of depth v/s pressure, stroke lengt

Regression equation in for depth in uncoded units:

Cryogenic Depth (mm) = -1.188 + 0.989 Pressure(Bar) - 0.00896 Stroke Length(mm)
- 0.0650 Pressure(Bar)*Pressure(Bar)
+ 0.000022 Stroke Length(mm)*Stroke Length(mm)
+ 0.000025 Pressure(Bar)*Stroke Length(mm)

Normal Depth (mm) = -1.097 + 0.999 Pressure(Bar) - 0.00983 Stroke Length(mm)
- 0.0650 Pressure(Bar)*Pressure(Bar)
+ 0.000022 Stroke Length(mm) *Stroke Length(mm)
+ 0.000025 Pressure(Bar)*Stroke Length(mm)

Regression equation for "Cryogenic Depth" suggests that pressure has the highest effect on depth as the constant value of it is 0.989. So a small variation in pressure can cause large change in stamping depth. Similarly pressure also shows highest impact on "Normal Depth" with the constant of 0.999.

Regression equation for surface roughness in uncoded Units:

Cryogenic Surface Roughness (µm) = 4.07 - 1.494 Pressure(Bar) + 0.0108 Stroke Length(mm)
+ 0.1038 Pressure(Bar)*Pressure(Bar)
- 0.000023 Stroke Length(mm)*Stroke Length(mm)
+ 0.000157 Pressure(Bar)*Stroke Length(mm)

Normal Surface Roughness (µm) = 4.61 - 1.552 Pressure(Bar) + 0.0102 Stroke Length(mm)
+ 0.1038 Pressure(Bar)*Pressure(Bar)
- 0.000023 Stroke Length(mm)*Stroke Length(mm)
+ 0.000157 Pressure(Bar)*Stroke Length(mm)

Regression equation for "Cryogenic Surface Roughness" suggests that pressure has the highest effect on depth as the constant value of it is 1.494. So a small variation in pressure can cause large change in stamping depth. Similarly pressure also shows highest impact on "Normal Surface Roughness" with the constant of 1.552.

Now, composite desirability of the parameters can be calculated for each iteration and result is as below:

$D = (d_1 \times d_2 \times d_3 \times \ldots\ldots \times d_n)^{1/n}$

Table 5. Composiet Desirability table

PtType	Blocks	Pressure (Bar)	Tool	Stroke Length (mm)	Depth (mm)	Surface Roughness (µm)	Composite Desirability
1	1	4	Normal	200	0.79	1.270	0.000000
1	1	4	Normal	250	0.81	1.275	0.000000
1	1	4	Normal	300	0.95	1.263	0.191416
1	1	4	Cryogenic	200	0.83	1.206	0.289892
1	1	4	Cryogenic	250	0.86	1.242	0.310715
1	1	4	Cryogenic	300	1.05	1.113	0.446733
1	1	5	Normal	200	1.20	0.800	0.695938
1	1	5	Normal	250	1.24	0.895	0.687733
1	1	5	Normal	300	1.27	0.763	0.757662
1	1	5	Cryogenic	200	1.27	0.421	0.750445
1	1	5	Cryogenic	250	1.33	0.671	0.752232
1	1	5	Cryogenic	300	1.47	0.526	0.822036
1	1	6	Normal	200	1.50	0.389	0.905246
1	1	6	Normal	250	1.52	0.263	0.897507
1	1	6	Normal	300	1.66	0.313	0.950940
1	1	6	Cryogenic	200	1.52	0.326	0.931644
1	1	6	Cryogenic	250	1.54	0.373	0.930608
1	1	6	Cryogenic	300	1.75	0.365	0.986334

Table 6. Response optimization table

Response Optimization: Surface Roughness(µm), Depth(mm)					
Response	Goal	Lower Target	Upper Target	Weight	Importance
SurfaceRoughness(µm)	Minimum	0.263	1.275	0.5	1
Depth (mm)	Maximum	0.79	1.75	0.5	1

Table 7. Composite Desirability Solution

Solution Based on Composite Desirability						
Solution	Pressure	Stroke Length	Tool	Surface Roughness Fit	Depth Fit	Composite Desirability
1	6	300	Cryogenic	0.309614	1.74236	0.986334

Based on Desirability Functional Approach (DFA), the solution we get is of 0.986334 composite desirability which is very near to 1.0. It means with the help of this interaction we can obtain desired response parameters. After getting the parameters and their interactions, these parameters were implemented and confirmation run was conducted and its stamping depth and surface roughness has been measured by the same instruments. Results of surface roughness and depth are 0.311 µm and 1.73 mm respectively.

Fatigue Analysis

Fatigue life analysis evaluates the impact of cyclic loads on the structural life of a product to ensure it meets requirements for performance, quality, and safety. There are several theories by which we can calculate or we can predict the fatigue life at which the component will tend to fail. These four theories are Goodman theory (England, 1899), Soderberg theory (USA, 1930), Gerber theory (Germany, 1874) and Morrow theory (USA, 1960). Here in this analysis goodman theory has been used because of its simple calculation and slightly conservative values. For fatigue analysis first of all geometry and meshing are developed for the components then maximum and minimum principal stress are identified and fatigue life is calculated for the same components.

(1) Ultimate tensile strength:

For low and medium strength of steel with low brinell hardness (<500 BHN), ultimate tensile strength can be approximated as,

S_u=3.45 x BHN

So ultimate tensile strength for untreated EN8 (for 223 BHN),

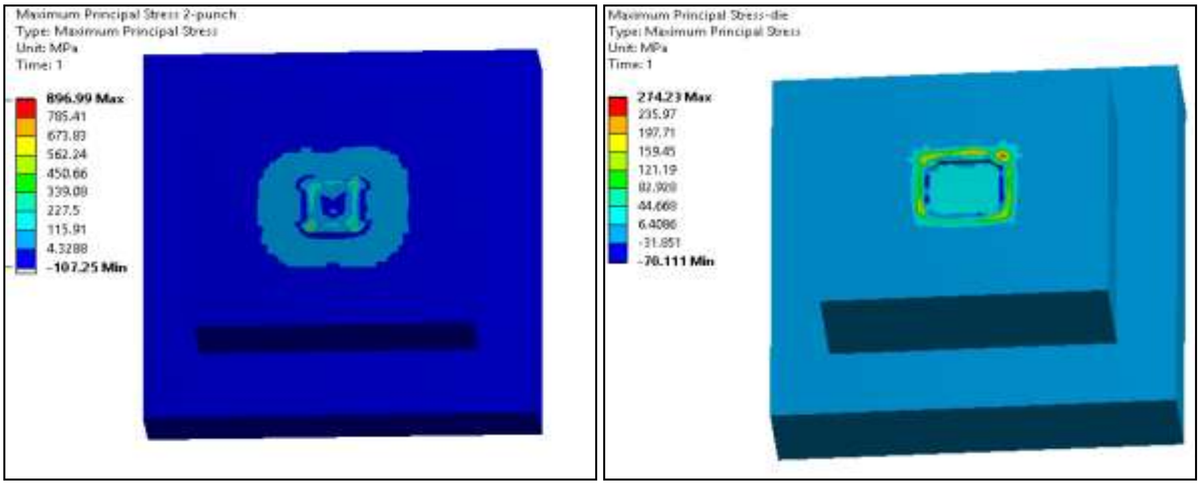
S_u=3.45 x 223

$\therefore S_u$=769.4 Mpa

And after for treated EN8 (for 310 BHN) is,

S_u=3.45x310

$\therefore S_u$=1069.5Mpa



(a) *(b)*

Figure 9. Maximum principal stress in punch (a) and die (b)

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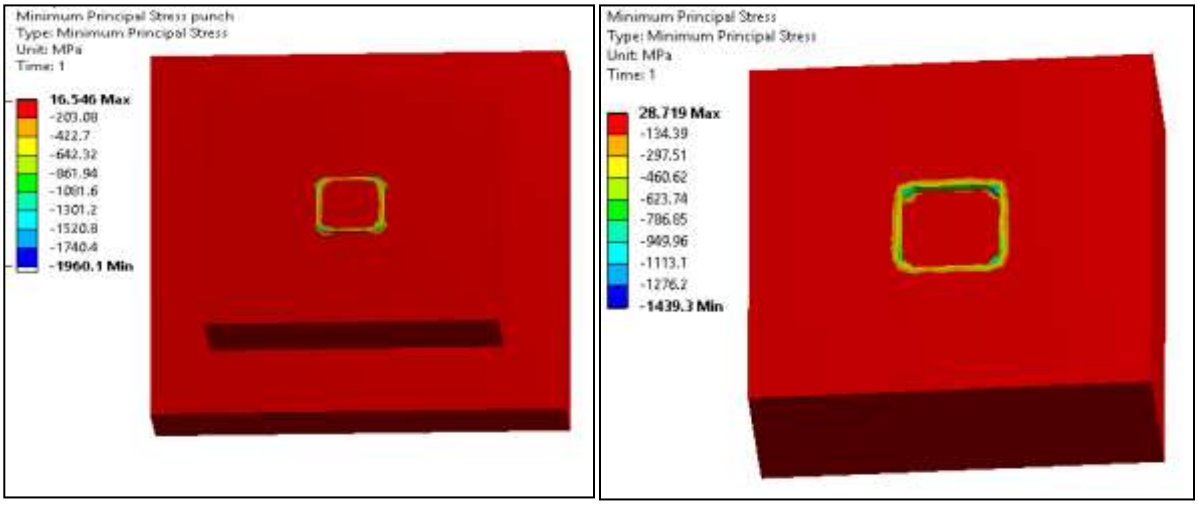

(a) *(b)*

Figure 10. Minimum principal stress in punch (a) and die (b)

(2) Endurance Stress (S_e):

S_e=0.5 x Ultimate tensile stress

$\therefore S_e = 0.5 \times S_u$

For untreated EN8 Endurance stress,

$\therefore S_e$=384.7 MPa

And for treated EN8,

$\therefore S_e$=534.8 MPa

(3) Now maximum principle stress S_{max}=520 MPa and minimum principle stress S_{min}=0 MPa which are kept same for the both treated and non treated components.

(4) Stress Amplitude is one-half of the stress range and it can be calculated as,

$$S_a = \frac{\Delta S}{2} = \frac{Smax}{2}$$

$\therefore$ S_a= 260 MPa (for both EN8)

(6) Mean Stress:Mean Stress is the algebraic mean of the maximum and minimum stress in the cycle.

$$S_m = \frac{Smax+Smin}{2}$$

$\therefore$ S_m=260 MPa (for both EN8)

(7) Stress ratio R is defined as the ratio of the minimum cyclic stress over the maximum cyclic stress.

$$R = \frac{Smax}{Smin}$$

$$R = \frac{0}{520}$$

So, R=0 (for both tool)

So, in this case A=1 and R=0

For this case constant amplitude load cycle will be as shown in figure 11.

Figure 11. Constant Amplitude load cycle

Now according to Goodman theory, the goodman formula can be stated as,

$$\frac{Sa}{Se}+\frac{Sm}{Su}=1$$

For Untreated component,

S_a=260 MPA, S_m=260 MPa and S_u=769.4 MPa

$$\frac{Sa}{Se}+\frac{Sm}{Su}=1$$

$$\therefore \frac{260}{Se}+\frac{260}{769.4}=1$$

$\therefore$ S_e = 392.7 MPa

For treated component,

S_a=260 MPA, S_m=260 MPa and S_u=769.4 MPa

$$\frac{Sa}{Se}+\frac{Sm}{Su}=1$$

$$\therefore \frac{260}{Se}+\frac{260}{1069.5}=1$$

$\therefore$ S_e = 343.5 MPa

(11) When plotted as a log-log scale of stress amplitude and number of cycles, the S-N curve will be a straight line as shown in figure 12. A power law equation can then be used to define the S-N relationship.

$N_1= N_2(\frac{S1}{S2})^{1/b}$

Where b is the slope of line referred as "Basquin Slope", which is given by,

$b= \frac{-(\log S1 - \log S2)}{(\log N2 - \log N1)}$

The power relationship is only valid for fatigue lives that are on the design line. For ferrous metals this range is from$1x10^3$ to $1x10^6$ cycles. For non-ferrous metals, this range is from $1x10^3$ to $5x10^8$ cycles.

So, for untreated component Basquin slope is,

$b= \frac{-(\log S1 - \log S2)}{(\log N2 - \log N1)}$

$b= \frac{-(\log 392.7 - \log 384.7)}{(\log 10\text{^}6 - \log 10\text{^}3)}$

$\therefore$ b= -0.09

And for treated component it is,

$b= \frac{-(\log S1 - \log S2)}{(\log N2 - \log N1)}$

$b= \frac{-(\log 343.5 - \log 534.8)}{(\log 10\text{^}6 - \log 10\text{^}3)}$

$\therefore$ b= -0.10

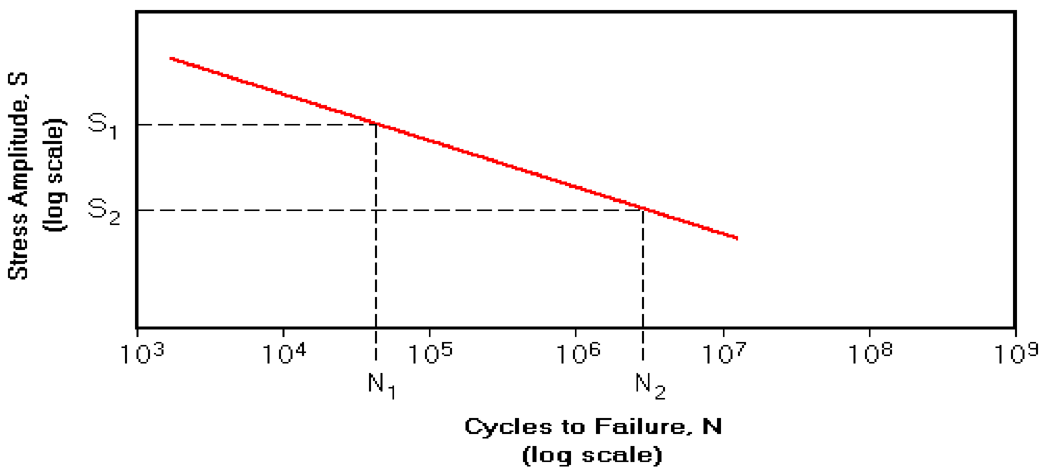

Figure 12. Idealize S-N curve

So, according to the power relation fatigue life of component can be calculated as:
Foruntreated punch,
$N_1= N_2(\frac{S1}{S2})^{1/b}$
According to generalized S-N curve theory N_1 is taken as 10^6 cycles:
$N_1 = 10^6(\frac{392.7}{384.7})^{1/-0.09}$
$\therefore N_1=7.84x10^5$ cycles (7.84E+05)

This numbers of cycles is in the range of finite life region ($<10^6$ cycles) means in this range component can fail at any point.
For treated punch,
$N_1= N_2(\frac{S1}{S2})^{1/b}$
$N_1= 10^6(\frac{343.5}{534.8})^{1/-0.10}$
$\therefore N_1= 8.23x10^7$ (8.23E+07)

This numbers of cycle is in the range of infinite life region ($>10^6$ cycles). It menas that after this range it is considered as infinite fatigue life. Values of different parameters for treated and untreated tools are as shown in table 8.

Table 8. Comparisons of calculated values before and after cryogenic treatment

Sr. No	Properties	Before	After	Unit
1	Hardness	223.0	310.0	BHN
2	Ultimate Stress (S_u)	769.4	1069.5	MPa
3	$S_{1000}(0.9S_u)$	692.4	962.6	MPa
4	Endurance (S_e)-S_2	384.7	534.8	MPa
5	Max. Principle (S_{max})	520.0	520.0	MPa
6	Min. Principle (S_{min})	0.0	0.0	MPa
7	Stress Amplitude (S_a)	260.0	260.0	MPa
8	Mean Stress (S_m)	260.0	260.0	MPa
9	Goodman Formula (Seq Amp)-S_1	392.7	343.5	MPa
10	Basquin Slope (b)	-0.09	-0.10	
11	Number of Cycle (N_2)	1.00E+06	1.00E+06	Cycle
12	Calculated Cycles (N_1)	7.84E+05	8.23E+07	Cycle

RESULT AND DISCUSSION

In this research work, cryogenic treatment has been carried out on EN8 steel at the temperature -196 ºC. It is observed that hardness has been increased from 223 BHN to 310 BHN. Its microstructure changes from austenite to martensite. Reason behind the improvement in mechanical properties is the change in its microstructure from austenite to martensite. Statistical analysis and fatigue analysis has been carried out for specified operating conditions. Result of Statistical analysis shows that pressure and tool are significant factors for surface roughness. Stroke length is not affecting parameter for this. As pressure increases surface roughness decrease and when cryogenic tool used, surface roughness is lower than normal tool. For stamping depth all three parameters are proved to be effective. Stamping depth increases with increase in pressure and stroke length. And also it has higher depth when we used cryogenic tool. So, by using cryogenic tool instead of normal tool we can achieve better stamped part with better surface finishing. According to Desirability Functional Approach (DFA), we can get 0.986334 composite desirability with pressure of 6 bar, cryogenic tool and 300 mm stroke length, which is very near to 1.0. It means with the help of this interaction we can obtain desired response parameters. In fatigue analysis, stress life approach theory is used to calculate fatigue life of punch. It is concluded that without using cryogenic treatment, punch life is 7.84E+05 numbers of cycles which is in the region of finite life and after cryogenic treatment it is 8.23E+07 numbers of cycles which is called as infinte life region as it crossed 10^6 cycles. It has been calculated numerically that after a cryogenic treatment of punch, its service life increases and this treatment has positive effect on fatigue life of the component.

CONCLUSION

Cryogenic treatment is an additional heat treatment which improves material's properties like hardness toughness and other surface properties. In this research work cryogenic treatment has been applied to EN8 steel tools and its increases from 223 BHN to 310 BHN. In statistical analysis, when cryogenic tool is used instead of normal tool we can get lower surface roughness and higher stamping depth at 6 bar pressure and 300 mm stroke length of tool. Also cryogenic treatment improves fatigue life on EN8 tools from 7.84E+05 numbers of cycles to 8.23E+07 numbers of cycles which is in the region on infinite life region.

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