EFFECT OF HARDNESS ON TENSILE STRENGTH OF V-NOTCHED SUP 9A BAR

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Abstract-This article summarised the tensile test of notched bars manufactured from SUP 9A Spring Steel. The effects of notch and hardness on the tensile strength of this spring steel have been examined. The experimental results indicate that fracture initiate at the notched section. Experimental result also indicates that there is an impact of variation of hardness on the tensile strength of material. After increasing the hardness tensile strength of material has been increased. The experimental test is done on Universal Testing Machine.

Keywords- Hardness; Notch Bar; Tensile Strength; SUP 9A; UTM.

I. Introduction

SUP 9A is a spring steel used to manufacture torsion bar or stabilizer bar. The chemical compositions of this material are Carbon 0.56-0.64%, Silicon 0.15-0.35%, Manganese 0.7-1% and Chromium 0.7-1%. Spring steel is used in some of the smaller aircraft's landing gear due to its ability to absorb the shock from landing and also acts like damping. Typical uses include saw blades, tape measures, helical springs, and vehicle suspension elements. Spring steel alloys feature the unique characteristic of being able to withstand considerable twisting or bending forces without any distortion. Products made from this steel alloys can be bent, compressed, extended, or twisted continuously, and they will return to their original shape without suffering any deformation. This characteristic is defined as high yield strength and is the result of the specific composition and hardening of the steel alloy. The other alloy additives typically include manganese and silicone with silicone being the key component in high yield strengths.

Notch is a small cut that is shaped like V and U and that is made on an edge or a surface. The notch effect increases stress in an area of a component near a crack, depression, etc. or a change in section, such as a sharp angle. It can be enough to cause failure of the component although the calculated average stress may be quite safe. Carpinteri et al., (2006) examined the behaviour of a notched round bar with a part-through crack under both tension and bending. The Stress Concentration Factor (SCF) due to the circumferential groove has been computed. In order to obtain the Stress-Intensity Factor (SIF) distribution for different values of the SCF and crack geometries, a three-dimensional finite element analysis has been performed. The notch effect on the SIF is significant for any crack size and shape. Fatigue life for a notched bar is shorter than that for an unnotched bar in the case of tension, while the opposite occurs in the case of bending. Zappalorto et al., (2008) concluded the analytical expressions for the notch stress intensity factors as due to deep circumferential sharp V-notches under torsion loading have been found starting from the expressions of the theoretical stress concentration factor of a hyperbolic notch.

II. Process

A. Heat treatment

Heat treatment is an operation or combination of operations involving heating at a specific rate, soaking at a temperature for a period of time and cooling at some specified rate. The aim is to obtain a desired microstructure to achieve certain predetermined properties (physical, mechanical, magnetic or electrical). Steels can be heat treated to produce a great variety of microstructures and properties. Generally, heat treatment uses phase transformation during heating and cooling to change a microstructure in a solid state. In heat treatment, the processing is most often entirely thermal and modifies only structure.

Quenching and Tempering: Martensitic transformation, more commonly known as quenching and tempering, is a hardening mechanism specific for steel. The steel must be heated above recrystallization temperature where the iron phase changes from ferrite into austenite, i.e. changes crystal structure from BCC (body-centered cubic) to FCC (face centered cubic). In austenitic form, steel can dissolve a lot more carbon. Once the carbon has been dissolved, the material is then quenched. It is important to quench with a high cooling rate so that the carbon does not have time to form precipitates of carbides. When the temperature is low enough, the steel tries to return to the low temperature crystal structure BCC. This change is very quick since it does not rely on diffusion and is called a marten sitictrans formation. Because of the extreme super saturation of solid solution carbon, the crystal lattice becomes BCT (body-centered tetragonal) instead. This phase is called marten site, and is extremely hard due to a combined effect of the distorted crystal structure and the extreme solid solution strengthening, both mechanisms of which resist slip dislocation.

Recrystallization Temperature:
0.5-0.7 T_m for recrystallization of alloy.

Where,
T_m is melting point in Kelvin of alloy.

B. Tensile Testing

The most common testing machine used in tensile testing is the universal testing machine. This type of machine has two crossheads; one is adjusted for the length of the specimen and the other is driven to apply tension to the test specimen. The machine must have the proper capabilities for the test specimen being tested. There are four main parameters: force capacity, speed, and precision and accuracy. Force capacity refers to the fact that the machine must be able to generate enough force to fracture the specimen. The machine must be able to apply the force quickly or slowly enough to properly mimic the actual application. The test process involves placing the test specimen in the testing machine and slowly extending it until it fractures. During this process, the elongation of the gauge section is recorded against the applied force. The elongation measurement is used to calculate the engineering strain, ε, using the following equation

$$\epsilon = \frac{\Delta L}{L_0} \quad \text{...} (1)$$

$$\epsilon = \frac{L - L_0}{L_0} \text{...} (2)$$

Where,
ΔL is the change in gauge length,
$L_0$is the initial gauge length,
L is the final length.
The force measurement is used to calculate the *engineering stress*, σ, using the following equation.

$$\sigma = \frac{F_n}{A} \text{...} (3)$$

Where,
F_n is the tensile force
A is the nominal cross section of the specimen.
The machine does these calculations as the force increases.

III. Literature Review

There are several types of experimental and research works have been developed to analyse the effect of hardness and notch on strength of alloy steels. In spite of the fact that the fracture tests on the notched bars have been conducted to analyse the effect of hardness on strength of bar but no studies have been found within the literature on SUP 9A. An extensive review and discussion of work have been done on the effect of hardness and of notch on strength of alloy steel. The details are as follows:

Nord et al., (1986) concluded stress intensity solutions for a surface flaw in a round bar and a threaded round bar. Loading cases include tension and pure bending. A finite element method, utilizing displacements in standard quadratic isoparametric elements adjacent to the crack edge, is used. The author presented results, in dimensionless format, which will be useful for determining fatigue life in various bolt and pin applications.

Zhang et al., (1992) concluded in terms of the spherical section by making an assumption, for an effective method for determining the local stress and limit load of a thick walled tube with an external hoop direction U shaped notch under tension, and discusses the relationships of the stress concentration factor with notch depth t, radius ϱ of the notch root and the internal radius of the tube. The expressions for the elastoplastic local stress and limit load are proposed.

Othman et al., (1993) studied constitutive equations in which the stress level dependence of creep rate is described by a sinh function, and two damage state parameters are used to model the tertiary softening caused by: (i) grain boundary cavity nucleation and growth, and (ii) the multiplication of mobile dislocations. These constitutive equations are applicable to polycrystalline nickel based super alloys and are used together with a continuum damage mechanics finite element based solver, DAMAGE XX, to study the behaviour of axis symmetrically notched tension bars and simulate the complex stress states that may be encountered at geometrical stress raisers in high temperature components. Numerical studies of such bars show that their behaviour can be accurately represented in terms of a 'skeletal effective stresses' located at a point within the notch throat, and the stress state at this point. Authors believe that this conclusion is valid not only for those materials that fail by grain boundary cavitation alone, but also for materials such as super alloys where grain boundary cavitation is accompanied by mobile dislocation multiplication.

Hayhurst et al., (1994) studied the range of applicability of the skeletal stress technique as a means of predicting the creep life time of a circumferentially notched tension bar subjected to steady load. The skeletal stress approach involves the quantification of the effective stress Σc and its ratio with the maximum principal tension stress Σl at a point, known as the skeletal point, at the throat of the notch. The stress Σc and stress state Σl/Σe at the skeletal point are assumed to remain constant and to determine the notched bar life time, which is determined by direct integration of the constitutive equations. It is also shown that the stress level applied to the bar, and the strength of the dislocations offending damage mechanism, denoted by a second damage variable ω1, also influences the above behaviour. Authors define the bounds of applicability for the skeletal stress approach to life time prediction, and recommended the use of complete CDM finite element analysis for those situations where breakdown occurs.

Lin et al., (1998) studied fatigue crack growth for various cracks in both unnotched and notched round bars by using an automated numerical technique, which calculates the stress intensity factors at a set of points on the crack front through the three dimensional finite element method and then applies an appropriate fatigue crack growth law to this set of points to obtain a new crack front. This technique also has the capability of automatic remeshing so that the crack propagation can conveniently be followed. A surface crack in different semi circularly notched bars under both tension and bending, a surface crack initiated from the root of a V notched bar and an initially twin crack configuration within a smooth tension bar. Some fatigue growth characteristics relevant to each type of cracks are also revealed. It is demonstrated that the fatigue growth analyses of various cracks commonly occurring in bars can reliably be made by using the automated finite element technique proposed.

Tanaka et al., (1998) studied the *R*-curve method for predicting the fatigue thresholds of notched components was under combined loading of cyclic torsion and tension-compression. The prediction was compared with the experimental data obtained from thin-walled tubular specimen with a hole under the combination of cyclic torsion and axial loading. The experimental data agreed well with the prediction both for crack initiation and fracture. The measured length of non-propagating crack had some scatter and the maximum length agreed fairly well with the predicted line. The non-propagating crack length normalized with the hole radius at the threshold stress for fracture was predicted fairly constant without respect to the hole size, while it varies slightly with the loading condition. The effect of the in-phase combination of axial and torsional stress loadings on the fatigue threshold was predicted by assuming the crack direction perpendicular to the maximum principal stress.

Lin et al., (1999) studied the shape of the fronts of surface cracks in semi circularly notched round bars under fatigue loading by a numerical procedure developed by the authors. This procedure utilizes a linear elastic three dimensional finite element analysis to estimate the stress intensity factor along the crack front, and then employs an experimental Paris type fatigue crack growth relation to calculate local crack advances at a few points along the crack front. Recreating a finite element model for the new crack front and repeating the calculation of the crack growth increment simulates further crack propagation. This method can avoid making the usually necessary assumption of crack shape during the fatigue life calculation for surface cracks in notched round bars. Both remote cyclic tension and bending loads are considered. Characteristics of the crack shape change are also investigated by examining deviations of the crack profiles from the widely assumed elliptical arc shape, and aspect ratio changes with crack growth.

Durmus et al., (2002) marked that circumferentially notched cylindrical specimens can be readily used for rapid determination of fracture toughness of metallic materials. Fracture toughness measurement of metallic materials by using circumferentially notched round specimens is observed to be an accurate and reliable procedure.

Carpinteriet al., (2004) studied the stress field in a structural component depends on the possible presence of a notch, and fatigue life may strongly be affected by geometric discontinuities. A circular-arc circumferential notch in a round bar is considered here, and the Stress Concentration Factor (SCF) related to both tension and bending is determined. Then, an elliptical-arc surface flaw is assumed to exist at the notch root and, for different values of SCF, the Stress-Intensity Factor (SIF) along the crack front is computed through a three-dimensional finite element analysis. The effect of the stress concentration on the SIF values is discussed for the considered crack configurations. Finally, the surface crack propagation under cyclic loading is examined through a numerical procedure which takes into account the computed SIF values.

Webster et al., (2004) studied and finite element calculations have been performed to obtain the creep stress distributions generated in circumferentially notched bar test-pieces. They have also been made to determine the relation between axial extension and notch throat diameter changes. It has been found that an approximate skeletal point can be identified where the stress state is insensitive to the power law stress dependence of creep. Consistent trends in skeletal point stress ratios to those given in an existing Code of Practice for notch bar creep testing have been obtained. In contrast the link between extension and notch throat diameter changes has been found to depend on the creep stress index as well as the notch geometry. It is anticipated that the analysis can be used to establish the multi-axial creep stress deformation and rupture behaviour of materials.

Atzori et al., (2006) studied the multi-axial fatigue strength of notched specimens made of C40 carbon steel (normalised state), subjected to combined tension and torsion loading, both in-phase and out-of-phase (Φ=0 and 90°). Authors tested V-notched specimens under two nominal load ratios, R=−1 and 0, while keeping constant and equal to the unity the biaxiality ratio, $\lambda=\sigma_a/\tau_a$. All specimens have the same geometry, with notch tip radius and depth equal to 0.5 and 4 mm, respectively, while the V-notch angle is equal to 90°. The results determined are discussed together with those deduced under pure tension or torsion loading on plain and notched specimens as well as on small shafts with shoulders. The application of an energy-based approach allows all the fatigue data obtained from the notched specimens to be summarised in a single scatter band, in terms of the total strain energy density evaluated at the notch tip against cycles to failure.

Carpinteri et al., (2006) analysed the influence of a circular arc circumferential notch in a pipe. Firstly, the stress concentration factor (SCF) is determined. Then, an elliptical arc external surface crack is assumed to exist at the notch root, and the stress intensity factor (SIF) along the surface crack front is computed for four values of the dimensionless notch radius and for several opening stress distributions on the crack faces. The effect of stress concentration on the SIF values is discussed for both thick and thin walled pipes.

Hayhurst et al., (2008) studied and concluded that two sets of constitutive equations are used to model the softening which takes place in tertiary creep of Nimonic 80A at 750^0 C. Softening by multiplication of mobile dislocations is firstly combined, for low stress, with softening due to nucleation controlled creep constrained cavity growth; and secondly combined, for high stress, with softening due to continuum void growth. The Continuum Damage Mechanics, CDM, Finite Element Solver DAMAGE XX has been used to study notch creep fracture. Low stress notch behaviour is accurately predicted provided that the constitutive equations take account of the effect of stress level on creep ductility. High stress notch behaviour is accurately predicted from a normalized inverse cavity spacing d/2 = 6, and an initial normalized cavity radius rhi = 3.16 · 10_3, where 2 is the cavity spacing, and d is the grain size; however, the constants in the strain rate equation required recalibration against high stress notch data. A void nucleation mechanism is postulated for high stress behaviour which involves decohesion where slip bands intersect second phase grain boundary particles. Both equation sets accurately predict experimentally observed global failure modes.

Carpinteri et al., (2008) studied the fatigue growth of a surface crack in a metallic round bar under cyclic tension or bending. The fatigue behaviour of the cracked bar is numerically determined by a step-by-step procedure. The propagation of an initial surface crack under cyclic tension or bending loading acting perpendicular to the crack plane is examined. The crack front is assumed to be described by an elliptical arc.

Carpinteri et al., (2009) studied a sickle shaped surface crack, also called crescent-moon (or crescent) crack, is assumed to exist at the root of a circular arc circumferential notch in a round bar under tension and bending. For different notch sizes (i.e. different values of the stress concentration factor), the stress intensity factor along the crack front is computed through a three dimensional finite element analysis. Authors examined the effect of the stress concentration factor for several crack configurations. Finally, the surface crack growth under cyclic loading is analysed through a numerical procedure that employs the stress intensity factor values obtained.

Tanaka et al., (2009) studied fatigue tests for circumferentially notched bars of austenitic stainless steel, JIS SUS316L, under cyclic torsion with and without static tension. For the case of cyclic torsion without static tension, the fatigue life of notched bars was found to be longer than that of smooth bars and to increase with increasing stress concentration under the same amplitude of the nominal torsional stress. This notch-strengthening effect is anomalous for the conventional fatigue design criterion. On the other hand, the fatigue life decreased with increasing stress concentration, when the static tension was superposed on cyclic torsion. For the case of cyclic torsion without static tension, the crack propagation life increased with increasing stress concentration, while the crack initiation life decreased. The anomalous behaviour of the notch effect was ascribed to the larger retardation of fatigue crack propagation by crack surface contact for sharper notches. The superposition of static tension reduced the retardation due to the smaller amount of crack surface contact, which gave rise well-known notch-weakening of the fatigue strength.

Wang et al., (2010) studied that on performing tensile tests at room temperature on 20 notched bars fabricated from constructional steel Q235 specified in Chinese National Standards. The effect of the notch radius, r, and that of the notch depth ratio, d/D, on the fracture model of the constructional steel is examined by the authors. The experimental results demonstrate that cracks initiate at the notched section. Specimens with a sharper notch radius (a smaller r) and a larger notch depth (a smaller d/D ratio) show poor ductility, but high fracture strength. The experimental data are further analysed using an elliptical yield model together with an elliptical fracture model originally proposed by the first author. The stress field computed from the numerical procedure indicates that the crack initiation occurs at the centre of the notched section which experiences the highest stress triaxially ratio (óm/óseq). As the stresses at the notched section reach the limiting values determined from the elliptical fracture model, macroscopic fracture failure in the notched bar occurs.

Wang et al., (2010) analysed the uniaxial tension tests for 20 notched bars fabricated from high strength steel Q345 specified in Chinese National Standards. The effects of the notch radius, r, and that of the notch depth ratio, d/D, on the ductility and fracture resistance of this high strength steel are examined. The experimental data are further analysed using a generalized yield model together with an elliptical fracture stress envelope originally proposed by the first author. The experimental results demonstrate that cracks initiate at the notched section, with the fracture surface filled with many dimples and shearing marks. Specimens with a sharper notch radius (a smaller r) and a larger notch depth (a smaller d/D ratio) show poor ductility, but high fracture strength. The stress field computed from the numerical procedure including the generalized yield model indicates that the crack initiation occurs at the centre of the notched section which experiences the highest stress triaxiality ratio ($\sigma m/\sigma seq$). As the stresses at the notched section reach the limiting values determined from the elliptical fracture criterion, macroscopic fracture failure in the notched bar occurs.

Tanaka et al., (2010) studied the two specific subjects related to the fatigue strength and life of notched bars under combined torsional and axial loading. The first subject is the fatigue thresholds of materials with small defects. The fatigue threshold of materials with small defects or sharp notches is not controlled by the initiation of fatigue cracks, but by their propagation. Authors believe that the *R*-curve method is very useful to predict the fatigue thresholds of notched components. A small crack nucleated at the notch root becomes non-propagating when the applied stress intensity factor drops below the resistance of the material. It is important that the *R* curve is independent of loading conditions and only the applied stress intensity factor depends on loading conditions. In the present paper, the *R*-curve method was successfully applied to predict the fatigue thresholds of holed tubes made of carbon steels under in-phase and out-of-phase combinations of cyclic torsion and axial loading. The second subject is an anomalous phenomenon of notch strengthening found in torsional fatigue of circumferentially notched round bars of austenitic stainless steel. In torsional fatigue of circumferentially notched bars of austenitic stainless steel, the fatigue life of notched bars was found to be longer than that of smooth bars and to increase with increasing stress concentration under the same amplitude of the nominal torsional stress. On the basis of the electrical potential monitoring of the initiation and propagation of small cracks at the notch root, the crack initiation life decreased with increasing stress concentration, while the crack propagation life increased.

Ohkawa et al., (2011) studied notch effect in austenitic stainless steel under cyclic torsion depending on the superposition of static tension. In pure torsion, the rubbing of the serrated factory roof type crack faces delays the crack growth along the notch root. Thus, the lifetime in notched specimen becomes longer than in smooth specimen. However, in cyclic torsion with static tension, the flat crack path and mean tensile stress reduce the influence of the crack face contact. Accordingly, shorter lifetime resulted from higher strain concentration at the notch root. Crack growth in low carbon steel under cyclic torsion is highly affected by the ferrite/pearlite banded microstructure besides the addition of static tension. Because of a small amount of the crack face contact, the reduction of lifetime in notched specimen is revealed irrespective of superposition of static tension.

Tanaka et al., (2014) studied circumferentially notched bars of austenitic stainless steel, SUS316L, and carbon steel, SGV410, with three different notch-tip radii and were fatigued under cyclic torsion without and with static tension. The torsional fatigue life of SUS316L was found to increase with increasing stress concentration under the same nominal shear stress amplitude. It is revealed that the crack initiation life decreased with increasing stress concentration, while the crack propagation life increased. The superposition of static tension on cyclic torsion causes notch weakening. The notch-strengthening effect in torsional fatigue was not found in carbon steels, SGV410. The difference in the crack path of small cracks near notch root between stainless steel and carbon steel gives rise to the difference in the notch effect in torsional fatigue. Under higher stresses, the fracture surface was smeared to be flat. The fracture surfaces of SG/V410 became smoother with increasing stress amplitude and notch acuity.

Chandra et al., (2014) studied modeling results for fatigue crack growths of a semi-elliptical surface crack in a V-shaped notchedround bar under uniform cyclic tension. All the analyses of modeling were carried out by using a software package featuring the boundary element method. The *J*-integral technique was used to compute the stress intensity factors (SIFs), and the NASGRO crack growth rate was chosen to simulate the fatigue crack growths. Mechanical and fracture properties of AZ-6A-T5 magnesium alloy were used for this analysis. Crack shape evolutions for different crack aspect ratios and the corresponding SIFs may be correlated to study the behaviour of crack growths. An unstable crack growth was observed when the evolving crack aspect ratio was between 0.6and 0.7.

Luo et al., (2015) studied the brazed structures having geometrical discontinuities like fillets working as notches. These notches have great effect on creep crack initiation and propagation. The notch effect on creep damage for HastelloyC276-BNi2 brazed joint, and the effects of notch type, notch radius and notch angle on creep damage have been investigated. The results show that the creep damage initiates in the filler metal. Different notch types bring different stress states, and generate different stress triaxialities and equivalent creep strains (CEEQs), leading to different creep damages. The maximum creep damage is generated in the notch tip for V-type notch. For U-type notch, the location of the maximum creep damage moves from the notch tip to the inside gradually as the not chradius increases. With the increase of notch radius and notch angle, the failure time of creep damage increases for U-type and V-type notches. The creep failure is prone to happen to V-type notch because it belongs to sharp notch.

Review revealed that several works has been done on austenitic stainless steel, SUS 316L, carbon steel, SGV410, and AZ-6A-T5 magnesium alloy. The researchers mainly focused on FEM and FDM analysis. In the analysis the fracture testing and fatigue testing is mainly focused. It has been observed in literature review that the analysis of hardness on the SUP 9A notched bar has not been performed that's why it is been observed that the analysis is needed to be done in this area. In this literature review, the relevant informations are summarized, including: the definition, development and application of notched bar, the mechanical properties of SUP 9A steels is analysed.

IV. Experimental Work

In this experimental work, the specimens with V notch (Figure 1) and after conducting heat treatment on electric furnace (Figure 2)is analysed on UTM (Figure 3) by conducting fracture test. The material of specimen is SUP 9A. The test is conducted on these specimens with v notch and hardness to analyse the effect of hardness and notch on strength of material. The specimens are manufactured with the details as mentioned in table 1.

V. Specification of Experimental Setup

The most common testing machine used in tensile testing is the universal testing machine. This type of machine has two crossheads; one is adjusted for the length of the specimen and the other is driven to apply tension to the test specimen. The machine must have the proper capabilities for the test specimen being tested. There are four main parameters: force capacity, speed, and precision and accuracy. Force capacity refers to the fact that the machine must be able to generate enough force to fracture the specimen. The machine must be able to apply the force quickly or slowly enough to properly mimic the actual application. The test process involves placing the test specimen in the testing machine and slowly extending it until it fractures. During this process, the elongation of the gauge section is recorded against the applied force.

Machine Specifications are as follows:

Model: AMT 20 UTM
Capacity: 20 Tonnes
Load Range: 0-20 kN
Least Count: 0.02 kN
Max. Dia.: 20mm
Min. Dia.: 6mm

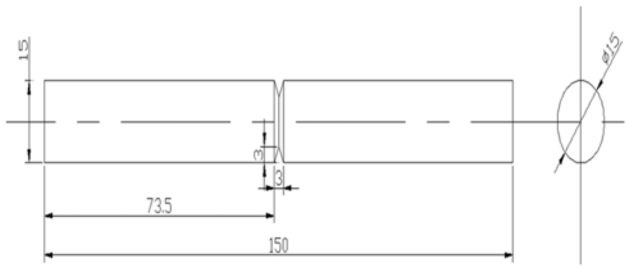

Figure 1: Specimen with V Notch

Figure 2: Electric Furnace

Figure 3: Experimental setup of fracture test

S. No.	Specimen V Notch	Hardness (HRC)	Load (kN)	Displacement (mm)
1	√	15	123.28	40.59
2	√	35	91.30	42.48

Table 1

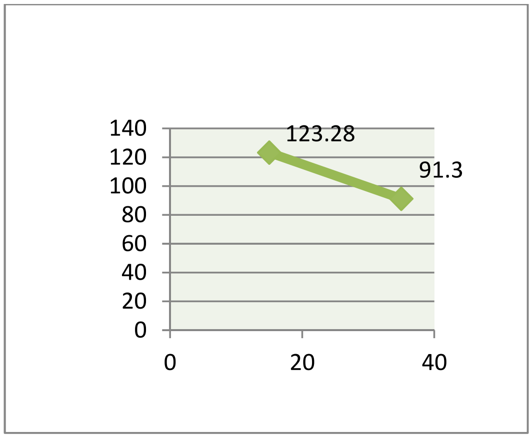

Figure 4: Relation between Hardness and Tensile Strength

VI. Conclusion

After conducting experiments, it can easily be concluded that there is impact of change of hardness on tensile strength of material. Graph (figure 4) shows that after increasing the hardness of notched SUP 9A turned bar, tensile strength of bar is decreased. This paper may be helpful for industry and research & development department to analyse the effect to hardness on notched bar.

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