Finite Element Simulation Of Small Punch Test To Determine Influence Of Key Test Parameters Used In Steam Turbine Blade Material

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***Abstract* - This research paper presents a finite element simulation of small punch test to determine the influence of key test parameters used in steam turbine blade material. To estimate the realistic remaining life of in-service equipments of thermal, petro-chemical, remnant and nuclear power plants etc, the degraded material properties of these equipments must be precisely known. In this research work, influence of numerous key test parameters is studied on flat samples using finite element simulations and their effects are significantly observed. In order to assess the strength of aged material during the service life, Small Punch Test has emerged as a powerful NDT tool of engineers. SPT is carried out for material CA-6 NM (Cromium-Nickle) alloy (used as blade material in steam turbines).The stress-strain curves area recorded for CA-6 NM (Cromium-Nickle) alloy in the temperature range 25-600 ^{0}C. As experimentation process in ASTM tests and SPT is mind-numbing and time consuming, finite element simulation of small punch test is carried out to have large number of load-deflection-temperature data.**

***Keywords* – Finite element simulation, Miniature testing method, small punch test, steam turbine blade material CA-6 NM, Modeling.**

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1. Introduction

Remaining life assessment methods are usually conventional principally for safety reasons, but also because of uncertainties arising from the lack of data for the mechanical properties specific to the components, as well as to substantial scatters in material properties resulting from manufacturing variables and technologies functional to produce these machineries.

Blades are the spirit of a steam turbine, as they are the primary elements that convert the thermal energy into kinetic energy. The efficiency and consistency of a turbine depend on the proper design of the blades. It is therefore necessary for all engineers involved in the steam turbines engineering to have an overview of the importance and the basic design aspects of the steam turbine blades. A total development of a new blade is therefore possible only when experts of all these fields come together as a team. Efficiency of the turbine is depends on the parameters are, Inlet and outlet angles of the blade, Blade Materials, Profile of the blade and Surface finishing of the blades etc.

Determination of accurate mechanical properties of operating components like turbine blades is a key element for the enhancement of component reliability, optimization of operating procedures and inspection intervals. This examination has therefore been undertaken to evaluate the potentially of the small punch test to asses material properties for miniature sized specimens. The small punch test procedure using inverse modeling technique will be used for mechanical characterization of thermal power plants components material in operating conditions.

In this present research work, analytical formulations have been used to describe the influence of key test parameters used in steam turbine blade materials and comparing small punch test results with ASTM tensile test results. Simulations of the behavior of small punch load-deflection have been made on CA-6 NM (Cromium-Nickle) alloy in the temperature range 25-600 ^{0}C.As, SPT experimental output shown by load-stroke curve with different temperatures in which yield load, peak load and their corresponding displacements are recorded. Furthermore these formulations have been used to estimate the various test parameters in a particular temperature range..

I. Material Properties and compositions

The following tables shows the material properties and compositions of blade material CA6NM :

Table 1 Room-temperature mechanical properties of cast corrosion-resistant alloys

Alloy	**CA6NM**
Heat Treatment	>966 ^{0}C, Air Cooled, Tempering
Tensile Strength	827mpa
Yield Strength 2% Offset	629 Mpa
Elongation In 50 Mm,%	24
Reduction In Area, %	60

Hardness, HB	269
Charpy Impact Energy	94.9 Joule
Mass Density , Kg/mm^3	0.0000078795

Table 2 Compositions and microstructures of corrosion-resistant high-alloy cast steels

Alloy - CA-6 NM (Cromium-Nickle) Microstructure - Tempered Martensitic

Composition, %	**Cr**	**Ni**	**Mo**	**Si**	**Mn**	**P**	**S**	**C**
	11.5-14.0	3.5-4.5	0.40-1.0	1.00	1.00	0.04	0.03	0.06

II. Test Parameters

The following six test parameters and their variation are accounted in the simulation study –

a. Fillet radius = 0.1, 0.3 mm
b. Ball diameter = 0.9 mm
c. Sample thickness = 0.24,0.26 mm
d. Friction = 0.1, 0.3 (Coulomb)
e. Temperatures = 300, 600 ^{0}C

Some key parameters having large influence should be identified so that more attention can be given to these parameters only to avoid blade failure.

2. Literature Review

The purpose of this literature review is to gain insight into the published work small punch test with finite element simulation to evaluate the key parameters involving mechanical properties of in-service components. It aims to pay special attention on detailed analysis of the literature in order to identify the existing gaps in the SPT literature and to formulate the objectives and scope of this present research work. Miniature test techniques are currently used as innovative tool of mechanical characterization under different conditions. Although, many researchers are working in the area of mechanical characterization using miniature test method still, they are not confident regarding the accuracy of the test results and correctness of test procedure.

SPT have been used mainly for determination of yield strength, ultimate tensile strength, flow properties, ductile to brittle transition temperature, fracture strain and creep properties of metals and alloys. The major contributions of researchers working in the field of material characterization using Small Punch Test are discussed below.

Baik et al. (1986) described the small punch load – deflection an experimental result for ductile-brittle transition temperature measurement of temper embrittled Ni-Cr steels. **E.Fleury** and **J.S.Ha (1998)** established the results of the simulations on austenitic 12Cr-1Mo steels used in steam power plant in the range 25-600 0C. These formulations have also been used to estimate the uniaxial tensile stress –strain behavior of ferritic 2.25Cr-Mo and AISI 403 steels for experimental small punch load – deflection curves. Lee et al. (2002) evaluated mechanical properties of RPV clad by SPT. They developed empirical linear relationship between yield load, maximum load, yield stress and ultimate tensile stress.

Hussain (2003) employed small punch test on different materials having varieties of strength to establish a general relationship between the data obtained from small punch test and the yield strength. **Mats and Rolf (2004)** developed small punch test machine where the miniature disk specimens of 5 mm and 3 mm in diameter were examined to determine their yield strength for 1Cr-Mo low alloy steel and 18Cr-9Ni austenitic stainless steel. **Matocha (2007)** developed small punch test set up to determine the tensile properties of in service components. Sampling was carried out by Vitcovice Research and Development, Ltd. Using Rolls-Royce SSam TM – 2 scoop sampling machine.

Partheepan et al. (2008) presented a method for determining the flow behavior of a material in a virtually non-destructive manner. They designed a new dumb-bell shaped miniature specimen which helps in avoiding the removal of large sized material samples from the in-service components for evaluation of current material properties. Linse et al. (2008) presented a method for the identification of hardening parameters and WEIBULL-parameters in brittle and brittle-ductile transition region using small punch test. By analyzing its load-displacement-curve, material behavior was predicted. Using neural networks, an identification routine was developed, which avoids time consuming calculations with FEM during optimization algorithm.

Dymacek and Milicka (2009) performed numerical simulation creep small punch test. Comparison of results of creep small punch tests on miniaturized discs with results of their simulation by means of finite element method (FEM) was presented. Advanced heat-resistant chromium steel of type P91 was selected for the investigations. **Sehgal et al. (2010)** used finite element method to stimulate small punch test experiment. The experimental and FEM load displacement curves were compared and found in good agreement. They found that using FEM, it is easy to obtain such curves for different materials with known mechanical properties and database can be created. The experimental miniature specimen load displacement curve can be compared with the curves in the database and mechanical properties can be predicted without using empirical relations.

3. Research Methodology

The proposed research methodology used for present research work is based on quantitative approach using simulation methods. Simulation approach involves the construction of an artificial environment within which the relevant information and data can be generated. In small punch test, output is given in terms of load-stroke curve through which flow properties of material can be determined by using inverse engineering approach.

In this work, a simulation based FE analysis is performed to study the key test parameters on small punch test output. The various geometrical, process and material parameters are considered to determine the sensitivity on SPT output. The parameters having negligible effects on yield strength and ultimate strength should not be given much attention. But the parameters having considerable effects on yield strength and ultimate strength must be accurately set before the start of the test. To perform the study of influence of key test parameters on SPT output, flat samples of CA-6 NM (Cromium-Nickle) alloys are used. The actual experimentations of SPT is tedious and time consuming process. Therefore, Finite element analysis of small punch tests are carried out considering friction between punch and specimen.

Axisymetric FE models are prepared and FE analysis is carried out using different set of parameters obtained by the varying the temperatures. The load deflection curves obtained using FE model match with those obtained through SPT experiments. The AnSys software is used for FE analysis of small specimen of turbine blade material. In this way, the experimental tryouts can be reduced using FE analysis which minimizes time and labor involved in sample preparation and experimentation.

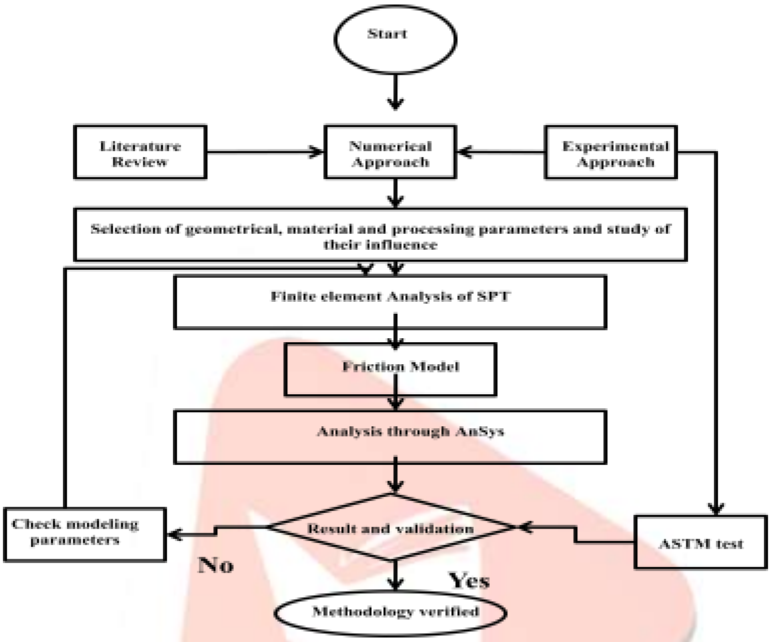


Fig.1 Methodology of proposed research work

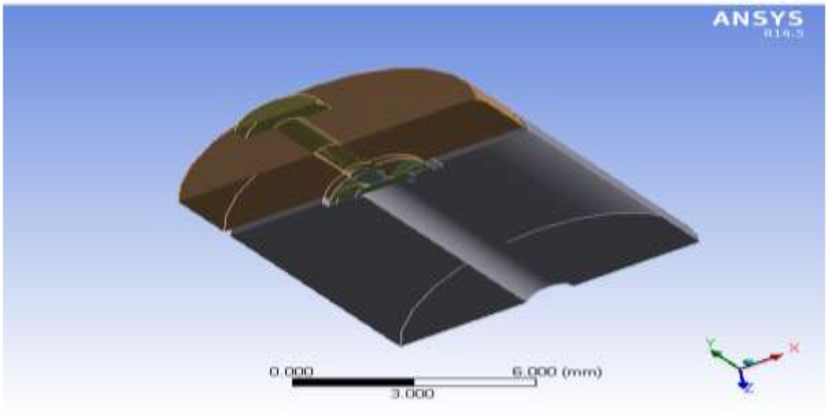


Fig.2 FE Model for the analysis

4. Results And Discussions

Finite element simulations are carried out by varying the key parameters considered here in the study. Based on FE simulation results, effects of various test parameters can be studied as follows:

I. Effect of temperature – FE simulation considering two different values of temperature 300 0C and 600 0C are carried out. From the fig. it can be inferred that values of stress is very small at very high temperature i.e. 600 0C but the curves are identical and yielding is occurring at the same time, very small effects can be seen with these two temperatures. It may be noted that stress developed in very small specimen shows very large variation with temperature for material CA6NM.

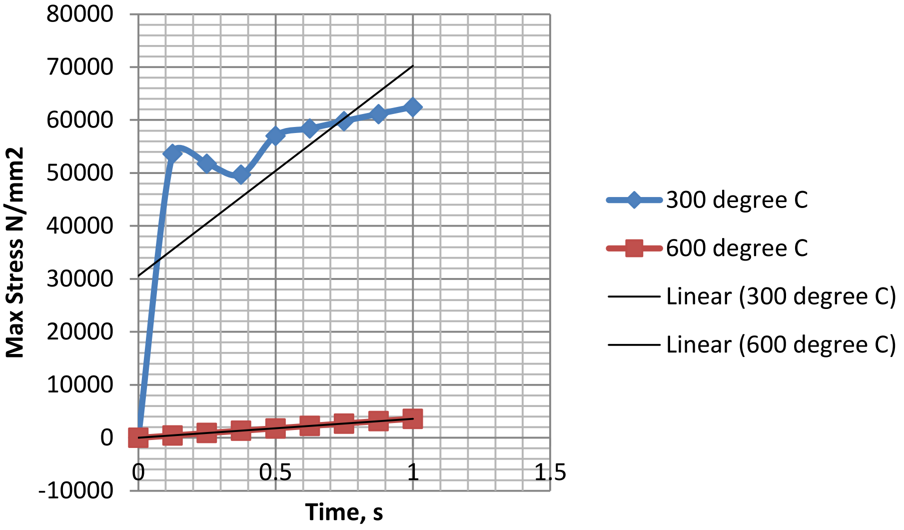


Fig. 03 - Max Stress vs time

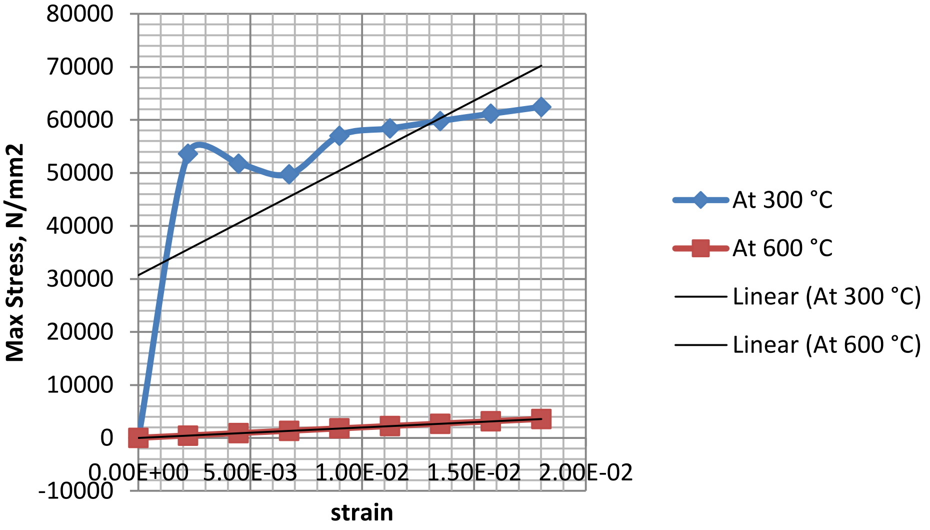


Fig. 04 - Maximum stress vs Maximum strain

II. Effect of fillet radius - FE simulation considering two different values of fillet radius 0.1 mm and 0.3mm are carried out. The maximum stress-time curves corresponding to these fillet radii are recorded which are shown in fig. The yield load is almost unaffected from fillet radius of die. Corresponding stroke increases with increase in fillet radius considerably because peak load decreases with increase in fillet radius. Thus depth of penetration in deformed specimen will be more at larger fillet radius whereas the peak load required for failure will be comparatively less.

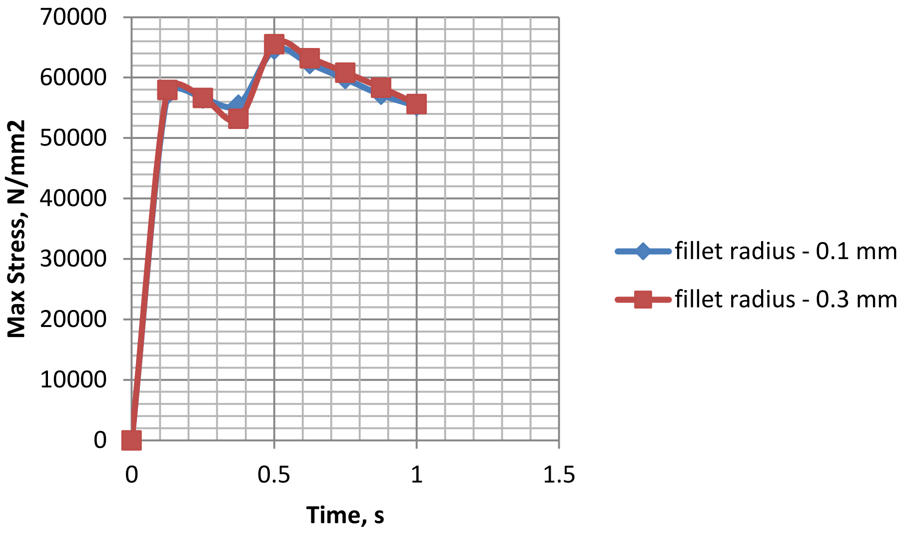
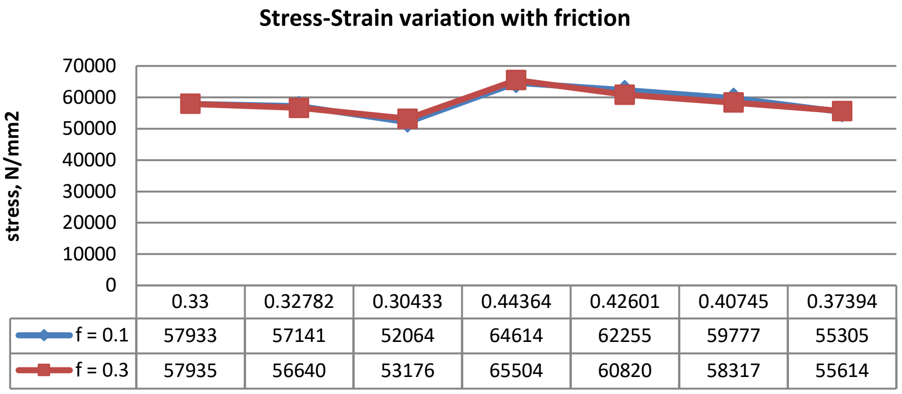


Fig. 05 - Stress variation with fillet radius

III. Effect of friction - FE simulation considering two different values of coloumb friction factor 0.1 and 0.3 are carried out. Stress-strain curves corresponding to various friction are shown in Fig. Peak load and stress and corresponding stroke are found to increase with an increase in friction. It has no effect on yield point. Thus the load required for yielding of specimen remains same for all the values of friction.



	0.33	0.32782	0.30433	0.44364	0.42601	0.40745	0.37394
f = 0.1	57933	57141	52064	64614	62255	59777	55305
f = 0.3	57935	56640	53176	65504	60820	58317	55614

Fig. 06 – Stress-strain variation with friction

IV. Effect of sample thickness - FE simulation considering two different values of sample thickness 0.24 mm and 0.26 mm are carried out. Stress-strain curves corresponding to various friction are shown in Fig. It can be inferred that yielding occurs at almost same yield load for all these different values of sample thickness. But maximum stress decreases with the increase of sample thickness. Thus the peak load required for the deformation of greater thickness sample would be more than that required for lesser thickness sample but the values of depth of penetration to deform samples will be same in all cases.

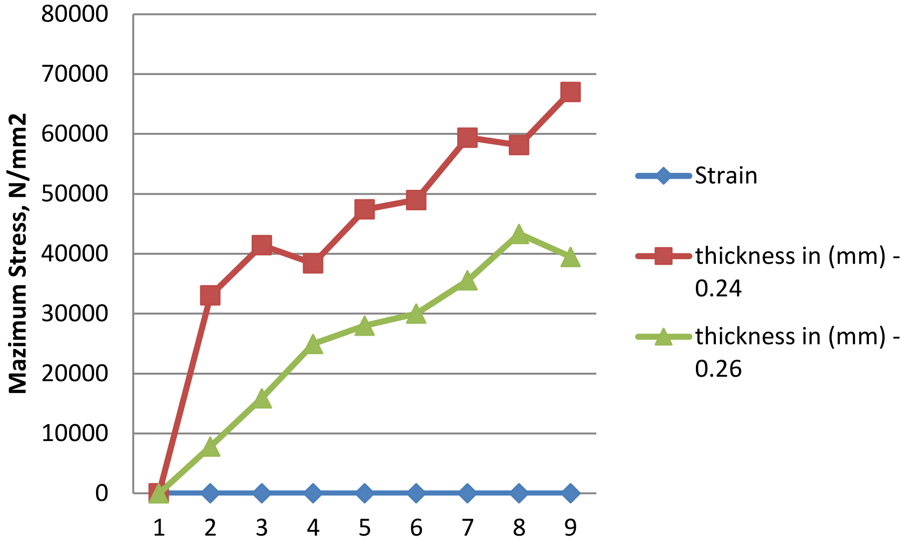


Fig. 07 - Stress-Strain variation with sample thickness

V. Effect of ball diameter –Deformation occurs at higher peak load if ball diameter is increased but depth of penetration of deformed sample remains unchanged for different ball sizes. Here , 0.9 mm ball diameter is taken for analysis.

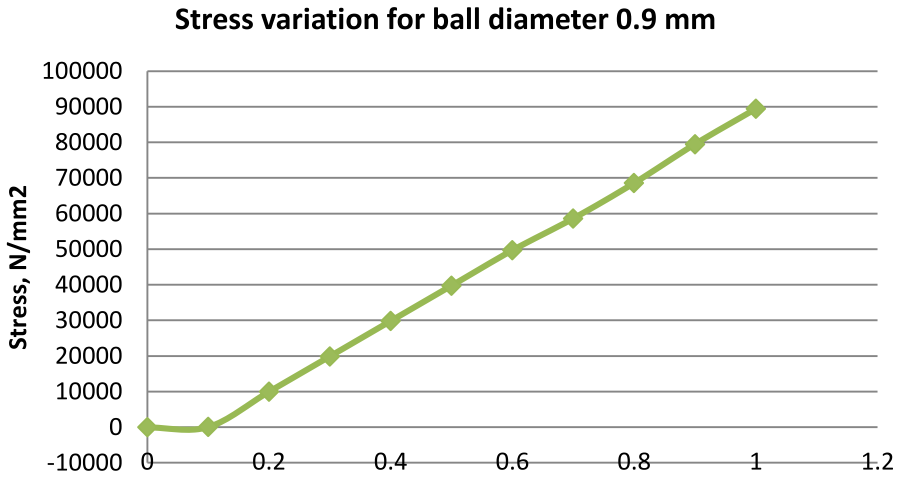


Fig. 08 - Stress-time variation with ball diameter 0.9 mm

5. Conclusion

With the aim of assessing the remaining life of steam turbine blades, FE simulation of small punch tests has been examined on a widely used material in a steam turbine. Analytical formulations demonstrated good agreement with experimental stress-strain-time curve for temperatures 300 0C and 600 0C. Linear relationship between stress and strain were obtained for material CA6NM in a low temperature range.

It is very difficult to sort out individuals share among all the parameters with the experimental stress-strain curves. However, based on these findings, sensitiveness of key test parameters may be studied for giving special attention during the test. In case of any deviation in these parameters, from the standard values, stress-strain curves may be scaled accordingly.

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