Experimental Investigation & Finite Element Analysis of Nano Notches Provided on Chip Surface

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Abstract **— The Thinning of the chips of the different materials has become necessary such as silicon chips in the solar cells. Surface defects are easily induced on chip during the thinning and machining processes. The stress concentration resulted from defects would be the source of crack and failure of silicon chips. In this paper, the finite element analysis & experimental investigation will be done to study the effect of nano notches on stress concentration caused by surface defect with different parameters for silicon chip. Since we will focus on the stress distribution near the defect and stress concentration factor. Nano notches will introduce in the nearby area of defect in the finite element analysis & experimental investigation. The chips will be under Tensile Testing and the stress distribution at crack tip on simple chip and chip with nano notches will be studied. Hence in this work we are going to analyse the Stress concentration factor due to the crack produced during the thinning operation of the chips will be minimize by the adding the nano notches and hence the life of the thin component or chips can be increase.**

Keywords **- Chip surface, crack, notches, stress concentration factor.**

Nomenclature
l - Length of chip
b - Crack depth
r - Radius of curvature at crack tip
N - Load in Newton
σ - Stress at crack tip
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I. INTRODUCTION

As use of solar energy becomes more mature and increasing day by day, it is important to pay more attention on energy conversion efficiency and reliability of solar cell. It is known that nano notches on solar cell surface can increase the anti-reflection and absorption efficiency of solar cell. However, less study was found for the relation between nano notches and mechanical strength of solar cell. In the process of thinning of solar cell would result in some small crack in the chip. These crack would easily be the origin of chip failure when under the external loads.

The cracks and the notches are the important reasons for the failure of the any component because at the tip of the cracks and the notches the stress generated is higher than the nominal stress. This phenomenon introduces the term stress concentration factor. To avoid the failures of the specimens

The study of the stress concentration factor gets vital importance. In 1952, Williams [5] use the Eigen solution expansion method to analyse sophisticated stress singularity of materials with single wedge. Sah[6]summarized many kinds of crack problems with different boundary conditions.[7]It was proved that stress concentration of v-shaped notch relaxed by nano notches.[8]Addis concluded that when building periodical structure on surface ,stress concentration on notch would change according to the geometric shape of structure. Chen[9]found that the strength of chips with surface nano notches were 2.5 times better than that of polished chips under bending test furthermore the chips with nano notches broke into several small pieces, in the contrary to the case for polishes chips, breaking into few big pieces. In this paper, the

Improvement of chip's mechanical strength and stress concentration reduction at crack tip by adding nano notches on chip surface is discussed.

Methodology:

To study the effect of nano notches Experimental Investigation of chip with a single crack and Nano-Notches Provided on Chip Surface has done.

Experimentation*:* For experimental study we select material as EN 24 plate with thickness of 1mm.selection of EN24 plate which is alloy of steel instead of silicon because silicon is very hard to machine by mechanical procedures. EN 24 steel is a high tensile alloy steel having high wear resistance. It is used in components subjected to high stresses. EN 24 plates having dimensions as follows:

Length of chip: 100 mm
Width of chip: 10 mm
Thickness of chip: 1 mm

Total 12 plates of EN 24 material are manufactured. In this process raw EN24 material is undergone through processes as follows:

Milling operation: milling operation has done to provide proper square shape of required size of raw EN24 material

Hardening**:** material is heated uniformly to 823 to 850^0 C until heated through. Quench in an oil.

After hardening operation the plates are subjected to grinding followed by surface grinding to make a surface smooth and to reduce its thickness. At last again milling operation has done to reduce thickness of plate to 1 mm.

MPI Testing**:** this is magnetic partial inspection testing done to detect the crack which can be produced during machining process. All the 12 plates are tested for MPI, out of which 2 plates having crack on it are selected for experimentation.

Wire cut method: one of the plate having crack on it is subjected to wire cut method to produce Nano notches on it. For this method smallest wire diameter size available is 0.25 mm. we select this size to provide nano notch on chip surface.

Width of crack: 1 mm
Length of crack: 5mm

Second chip is now provided with a Nano notches along with the centrally provided crack of width 0.25 mm. dimensions of Nano notches provided on both sides of central crack as follows:
Width of notch: 0.25mm
Depth of notch: 1 mm

Gap between crack and Nano notches is keep as 5mm.thus total no of notches & cracks are 19 on second plate. After all the processing and testing chips will look like as follows:

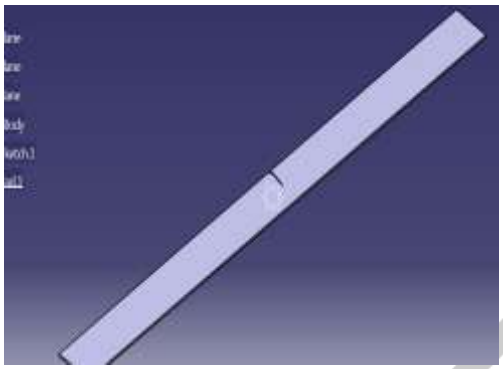


Fig. 1 *Chip with crack*

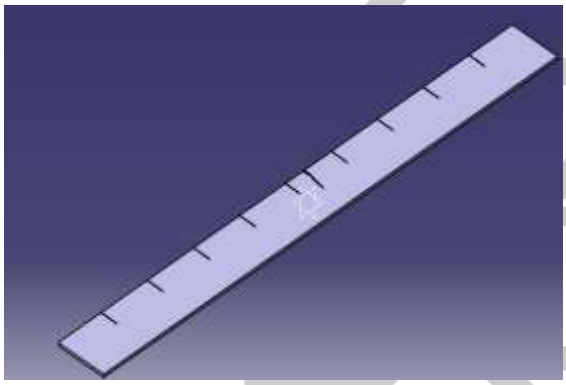


Fig.2. Chip with crack and notches

We consider tensile testing for checking performance of both the plates. For this plates are subjected to tensile loading conditions. While applying tensile load one face of the chip parallel to the crack and notches will be kept fixed and tensile load is applied on another side of chip. Tensile test is carried on both the plates with Universal Testing Machine. Cross head speed for this testing was 5 mm per minute. Various loads from o N to 800 N will be applied on both the plates to observe stress near crack tip. Stress value at which breaking of plates occurs is noted. With this reading other reading such as strain, displacement, and percent elongation were recorded.

Stress Concentration Factors:-

Theoretically stress distribution along a surface should be uniform but if abrupt changes in geometry occurs stress concentration factor will increase. It occurs for all kinds of stress, axial, bending or shear in presence of notches, holes & fillets. The maximum value of the stress at such condition is given by the elementary equation by stress concentration factor Kit

$$K_{it} = \frac{actual\ stress}{nominal\ stress}$$

Stress concentration factor calculated by this formula is called as theoretical stress concentration factor.

FEA Analysis:-

For FEA analysis model is selected with same dimensions as experimental model. FEA analysis is carried out using ANSYS 16.0 .we consider symmetric model; crack and notches are given from middle of the plate. Meshing element size in any is 1mm. tensile load of 800 N is applied same as that of experimental conditions. Material properties selected for analysis are as follows
EN 24
Density :- 7.8611e-06 kg/mm^3
Young's modulus: - 0.21
Poisson's Ratio: 0.3

Results are noted mainly for von mises stress acting on both the plates represented as follows

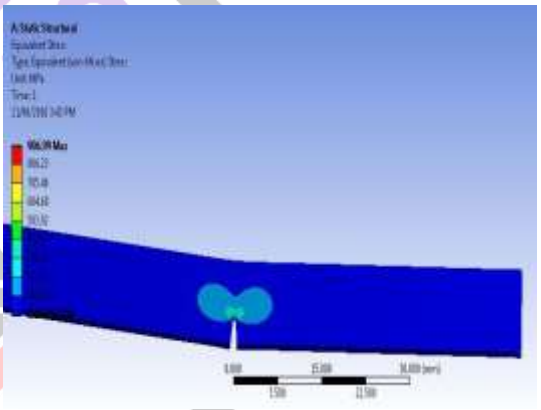


Fig no.3 structural analysis for plate no.1

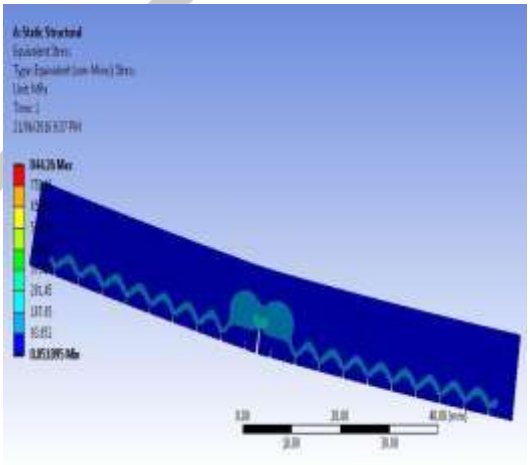


Fig no.4 structural analysis for plate no.2

Numerical Analysis:

I. $\text{Nominal stress} = \frac{Force}{Area}$

Here we consider the area near the tip surface where maximum stress are observed. This area will remain same foe both plates.

Area = 5mm x 1mm = $5mm^2$

I. Nominal stress = $\frac{800}{5}$ = 160 N/mm^2

Stress concentration factor = $\frac{actual\ stress}{nominal\ stress}$

Value of actual stress is taken from ansys results.

I. For Plate with a crack : $K_t = \frac{906.99}{160} = 5.65$

II. plate with a crack & notches:

$K_t = \frac{844.26}{160} = 5.27$

Experimental Validation: -

Experimental validation involves the non-destructive testing of plates for detection of crack after went through various mechanical operations. Finally tensile testing of plates was carried out using Universal Testing Machine in Praj Metallurgical Laboratory.

Fig 5 MPI Test of plates

Advantages of magnetic particle testing include the following:
(1) It does not need very stringent pre-cleaning operation.
(2) Best method for the detection of fine, shallow surface cracks in ferromagnetic material.
(3) Fast and relatively simple NDT method.
(4) Generally inexpensive.
(5) Will work through thin coating.
(6) Few limitations regarding the size/shape of test specimens
(7) Highly portable NDT method.
(8) It is quicker.

Some of the limitations of magnetic particle testing include the following:
(1) Material must be ferromagnetic.
(2) Orientation and strength of magnetic field is critical.
(3) Detects surface and near-to-surface discontinuities only.
(4) Large currents sometimes required.
(5) "Burning" of test parts a possibility.
(6) Parts must often be demagnetized, which may be difficult

Result of MPI Test:

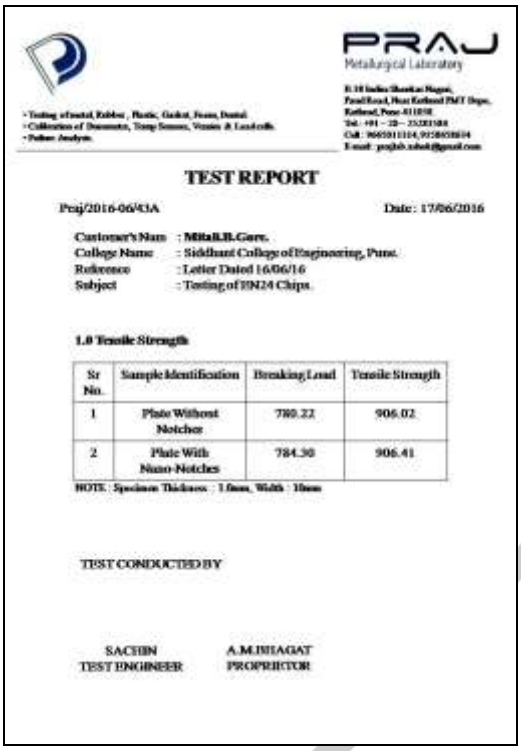
Fig. 6. Result of MPI Test

Tensile Test of plates:

We consider tensile testing for checking performance of both the plates. For this plates are subjected to tensile loading conditions. While applying tensile load one face of the chip. Parallel to the crack and notches will be kept fixed and tensile load is applied on another side of chip.

Fig. 7 Set up for testing of plates.

Result of Tensile Test:



PRAJ
Metallurgical Laboratory

TEST REPORT

Praj/2016-06/43A Date : 17/06/2016

Customer's Nam : MRaLB.Gore.
College Name : Siddhant College of Engineering, Pune.
Reference : Letter Dated 16/06/16
Subject : Testing of EN24 Chips

1.0 Tensile Strength

Sr No.	Sample Identification	Breaking Load	Tensile Strength
1	Plate Without Notches	780.22	906.02
2	Plate With Nano-Notches	784.30	906.41

NOTE : Specimen Thickness : 1.0mm, Width : 10mm

TEST CONDUCTED BY

SACHIN
TEST ENGINEER

A.M.JHAGAT
PROPRIETOR

Fig. 8. Result Of Tensile Test

RESULT & DISCUSSION:-

Results are recorded for stress concentration factors for tensile loading condition both plates are as follows

	Maximum stress by FEA (MPa)	Nominal Stress from (P/A) (MPa)	Stress concentration Factor
Chip Without nano notches	906.99	160	5.66
Chip With nano notches	844.26	160	5.27

Table 1: Results by FEA for EN24 plates

	Maximum stress by FEA (MPa)	Nominal Stress from (P/A) (MPa)	Stress concentration Factor
Chip Without nano notches	906.02	160	5.66
Chip With nano notches	850.52	160	5.27

Table 2: Results by Tensile test for EN24 plates

	Maximum stress by FEA (MPa)	Nominal Stress from (P/A) (MPa)	Stress concentration Factor
Chip Without nano notches	5302	500	10.60
Chip With nano notches	5232	500	10.42

Table 2: Results by FEA for silicon material

CONCLUSION:-

In this work we conclude that the Stress concentration factor due to the crack in the thin structures can be reduced by the nano notches technique.

The Stress concentration factor for the tensile loading that is reduced by around 20 % for the chip we studied.

The stress concentration factor for the tensile loading, compressive loading, and bending loading and for the torsional loading is different.

The stress concentration factor reduction is dependent on the size of the nano notches, number of the nano notches, the pitch of the nano notches and also the radius of the curvature at the tip of the notches.

In case study, the finite element analysis was used to investigate the stress concentration reduction at crack tip by adding nano-notches on chip surface.

The stress concentration factor at crack tip on silicon chip with Nano notches was found to reduce more than 40% for the case studied when compared to that without Nano notches and the mechanical strength of chip was improved also.

In case of the silicon chips used in the solar panels if we made the nano notches the heat transfer rate is also increased due to the area for the heat conduction is also increased. This is one of the important advantages of the nano notches.

This method of the reduction of the stress concentration is suitable for the so many applications where the thin structures are used. In the higher temperature applications also this method is helpful.

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