ISSN: 2349- 5197
Impact Factor (PIF): 2.138

INTERNATIONAL JOURNAL OF RESEARCH SCIENCE & MANAGEMENT

ANALYSIS OF SPALLING DEFECTS IN SPUR GEAR ON STRENGTH USING FINITE ELEMENT ANALYSIS

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Keywords: Spur Gear, Spalling, Number of teeth, Module, Pressure Angle, and Pro-Engineer.

Abstract
Two meshing gears are transmitting rotational motion as well as power. Any defect in gear will effect in variation of power and torque. Gear teeth fails due to forces and the contact between the two meting gears. Spalling is similar to destructive pitting except that the pits are usually larger in diameter and quite shallow. Present work deals with the analysis of effects of spur gear spalling defects on strength with variation of gear parameters using Finite Element Analysis. Modules, No of Teeth, Pressure Angle are considered for the analysis. For modeling and analysis CAD/CAM software Pro-Engineer Wildfire is used.

Introduction
Spalling is similar to destructive pitting except that the pits are usually larger in diameter and quite shallow. Often the spalled area does not have a uniform diameter. Spalling often occurs in medium-hard material as well as in highly loaded fully hardened material. Spalling of this kind should not be confused with “case crushing” which is associated with case hardened gear material.[1] In engineering and technology the term “gear” is defined as a machine element used to transmit motion and power between shafts by means of progressive engagement of projections called teeth. [2]
A gear is said to be failed when it can no longer efficiently do the job for which it was designed. Causes of failure may range from excessive wear to catastrophic breakage. [1]
The finite element method is capable of providing the design/redesign of the gear information, but the time needed to create such a model is large. In order to reduce the modeling time, a preprocessor method that creates the geometry needed and Pro-Engineer provides this functionality. The finite element method is very often used to analyze the stresses in an elastic body with complicated geometry, such as a gear.
In this work the analysis is done to study the effects of spalling defect on strength of involute spur gear with variation of gear parameters. First the gear with no defects i.e. healthy gears is analyzed with variation of one parameter (like no. of teeth etc) and keeping all other parameters same is analysed. Then the same procedure is adapted with a gear with defect. The modeling of healthy and defective gear is done in Pro-Engineering software and then finite element analysis is carried out by taking the load at the highest point of the single tooth contact. The distortion of each healthy and defective gear with loading are compared.

Literature survey
On this topic many scientists are working and many of them find methods to increase the strength of the gear. Rui Ma et al [3] focuses on the nonlinear dynamic and vibration characteristics of spur gear pair with local spalling defect to explore the spalling mechanism. Shengxiang Jia [4] this paper presents a 26 degree of freedom gear dynamic model of three shafts and two pairs of spur gears in mesh for comparison of localised tooth spalling and damage. This paper details how tooth spalling and cracks can be included in the model by using the combined torsional mesh stiffness of the gears. V. Spitas et al [5] did his work on spur gear teeth with circular instead of standard trochoidal root fillet is introduced and investigated numerically using FEA. M Koilraj et al [6] on the basis of their work gives the conclusion that, the stress correction factor and the form factor increase with the increase in positive profile correction. M. Savage et al [7] has propose a bending strength model for internal spur gear teeth, this model assist design efforts for unequal addendum gears and gears of mixed materials. Durmus Gunay et al [8] investigate that, it is possible to improve load carrying of gears by selecting the proper addendum modification coefficient. L. Kapelevich et al [9] optimize the fillet profile which allows reducing the maximum bending stress in the gear tooth root area by 10-30%. It works equally well for both symmetric and asymmetric gear tooth profiles. Y. Ding et al [10] in this paper, the development of a gear spalling depth prediction model are reported. The model is based on the ligament collapse spalling mechanism in gears.

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Modelling of gear

In total 28 numbers of gears are modelled in Pro/ENGINEER Wildfire [11], which are having the following parameters.

- Module –3 mm, 4 mm, 5 mm, 6 mm and 7 mm (Preferred Series)[1]
- No of Teeth – 15, 18, 20, 25 and 30[1]
- Pressure Angle - 14.5^0, 18^0, 20^0, and 24^0 [1]
- Defects – Spalling,

For modeling and analysis one parameter is varied and all other parameters are kept constant

The following steps are showing the procedure to model the gear of 15 numbers of teeth with the combination of the all above mentioned parameters in the Pro/ENGINEER Wildfire. Other set of gears are modelled in the similar way.

- Starting Pro/Engineer
- Preparing the sketch
- Defining Part Parameters
- Generation of Gear Blank
- Generation of Involutes Curve
- Cutting First Tooth Space
- Patterning the tooth Space
- Modeling the Gear with Circular fillet

These above mentioned steps referring from Mike Renfro [12] proposed a method for modeling of spur gear teeth in Pro/ Engineer Wildfire. Figure 1 showing the model of spur gear and figure 2 showing the model of spur gear with spalling defect.

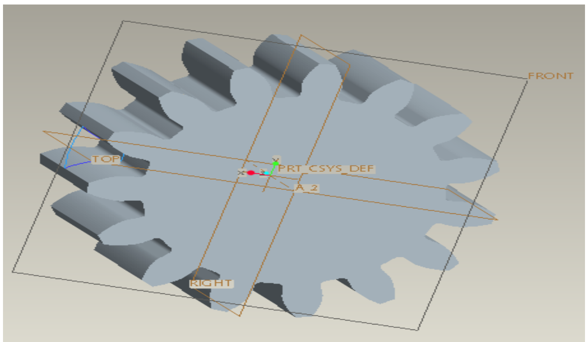

Fig. 1 Gear model with no defect

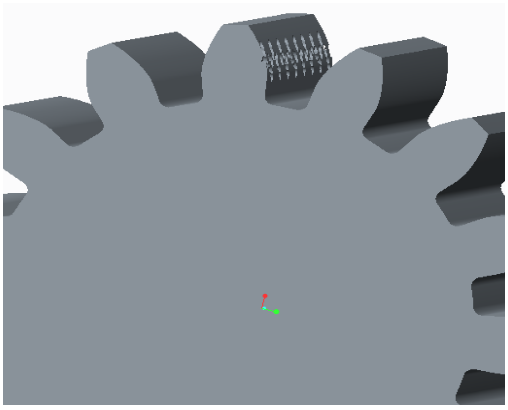

Fig. 2 Gear model with spalling defect

Other set of gears are modeled in the similar way.

Structural analysis

The structural analysis of the spur gear tooth model is carried out using the finite element analysis in Pro/Mechanica which is an application of Pro/Engineer [11]. The following steps are showing the procedures to structural analysis the gear of 15 numbers of

ISSN: 2349- 5197
Impact Factor (PIF): 2.138

INTERNATIONAL JOURNAL OF RESEARCH SCIENCE & MANAGEMENT

teeth in the Pro/Engineer, other set of gears are analysis in the similar way. The load applied at the highest point of single tooth contact as shown in the figure 3.

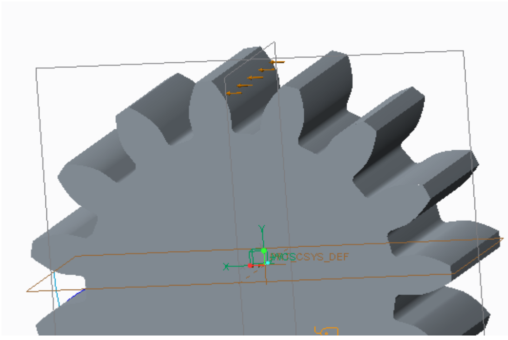

Fig. 3 Loading at HPSTC with 100N

All degree of freedom of the surface both side of the tooth being constrained. Figure 4, is showing the displacement constrained.

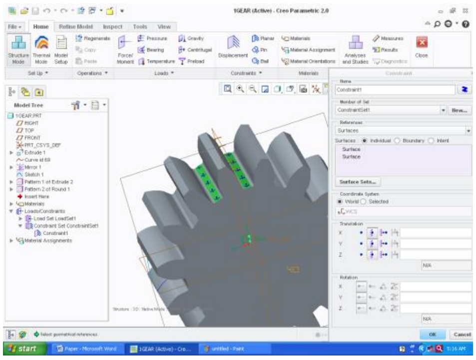

Fig. 4 Displacement Constraint

At the Aspect Ratio of 7 the Mess is generated with tetrahedron nodes. Total 165818 element and 31359 nodes are created. Figure 5, is showing mess generation. Maximum element size of 5 mm is selected for the Mess control.

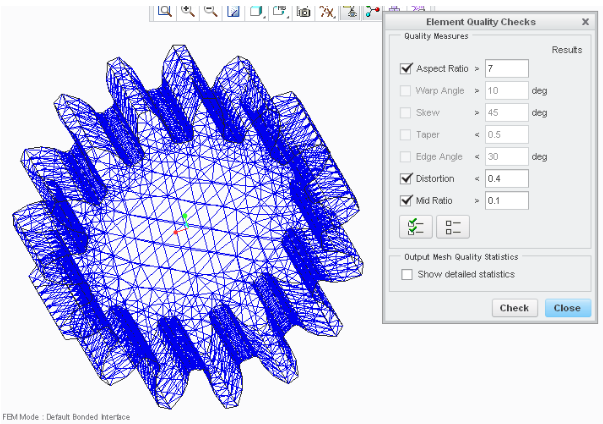

Fig. 5 Mess Generation

By applying the analysis over the surface which is facing the load we get the maximum and minimum distortion in the numeric as well as in the form of colour scheme. Figure 6, is showing the element quality check, the highlighted part which is the root of the gear is showing weak part of the gear it also describes the number of poorly shaped elements.

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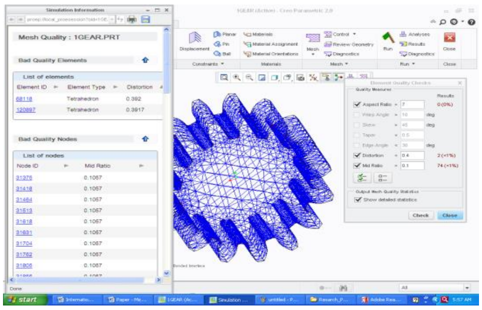

Fig. 6 Element Quality Check

Figure 7, showing the finite element analysis in terms of the colour scheme with value of distortion produced due to loading.

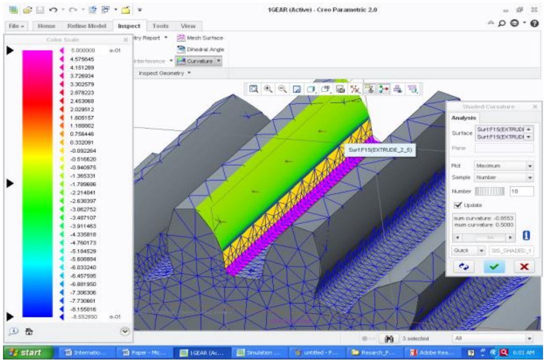

Fig.7 Finite Element Analysis Results

Result & discussion

CASE (I) - In the first case curvature deflection is shown in the form of value for healthy gear, when number of teeth increases. These values are showing in table 1.

Table 1(Healthy Gear)

S.No.	No. of teeth	Curvature Deflection (mm)
1	15	0.8553
2	18	0.7521
3	20	0.6972
4	25	0.5913
5	30	0.5146

Figure 8 is representing the graph between the number of teeth and Curvature Deflection for the healthy gear.

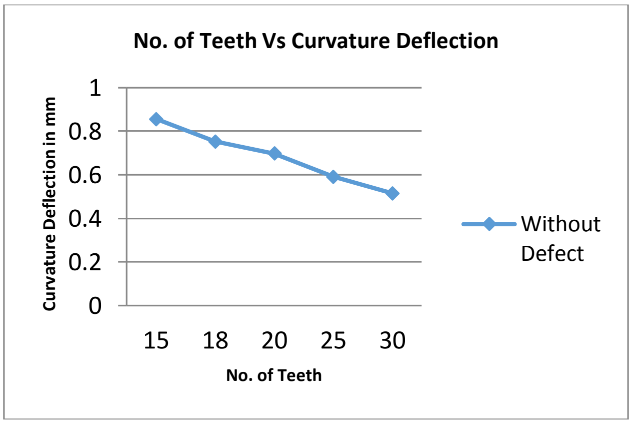

Fig. 8 No. of teeth Vs Curvature Deflection for Healthy Gear

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Now curvature deflection is shown in the form of value for defective gear like Spalling when number of teeth increases. These values are showing in table 2.

Table 2 (Spalling Defect)

S.No.	No. of teeth	Curvature Deflection (mm)
1	15	0.3343
2	18	0.2974
3	20	0.2779
4	25	0.2383
5	30	0.2202

Figure 9 is representing the graph between the number of teeth and Curvature Deflection for the defective gear.

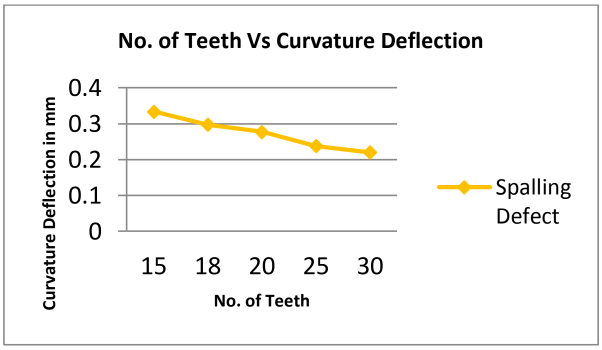

Fig. 9 No. of teeth Vs Curvature Deflection for Spalling Defect

Graph shown in the figure 10 in Case I, the effect of healthy and defective gears of different numbers of teeth is investigated; it shows the distortion produced in the gear of 15, 18, 20, 25, and 30 number of teeth

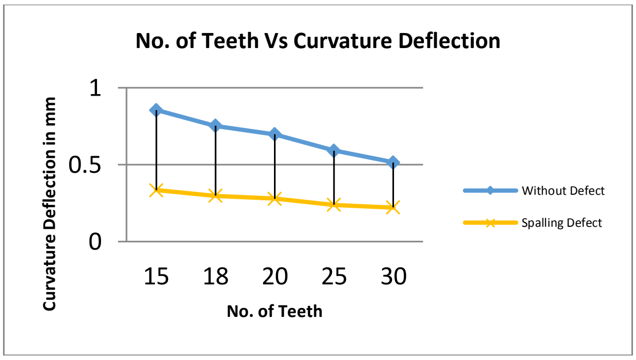

Figure 10 Graph No. of teeth Vs Curvature Deflection

Maximum deflection is shown by the gear having no defect i.e. without defect and minimum deflection is produced in the defective gear i.e. in the gear of pitting defect when number of teeth increases.

CASE (II) - In the second case curvature deflection is shown in the form of value for healthy gear, when module increases. These values are showing in table 3.

Table 3 (Healthy Gear)

S.No.	Module (mm)	Curvature Deflection (mm)
1	3	0.4648
2	4	0.3486
3	5	0.2789
4	6	0.2324
5	7	0.1992

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Figure 11 is representing the graph between the Module and Curvature Deflection for the healthy gear.

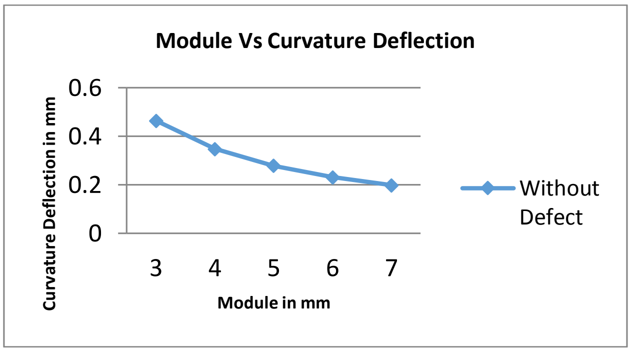

Fig. 11 Module V/s Curvature Deflection for Healthy Gear

Now curvature deflection is shown in the form of value for defective gear like Spalling when module increases. These values are showing in table 4

Table 4 (Spalling Defect)

S.No.	Module (mm)	Curvature Deflection (mm)
1	3	0.3181
2	4	0.2929
3	5	0.253
4	6	0.2187
5	7	0.1913

Figure 12 representing the graph between the number of teeth and Curvature Deflection for the defective gear.

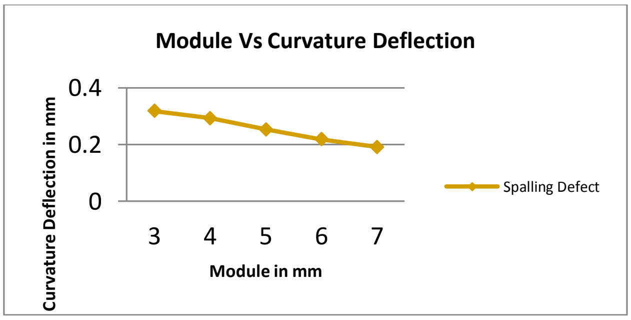

Fig. 12 Module V/s Curvature Deflection for Spalling Defect

Graph shown in the figure 13 in Case II, the effect of healthy and defective gears of different Module is investigated; it shows the distortion produced in the gear module of 3mm, 4mm, 5mm, 6mm, and 7mm.

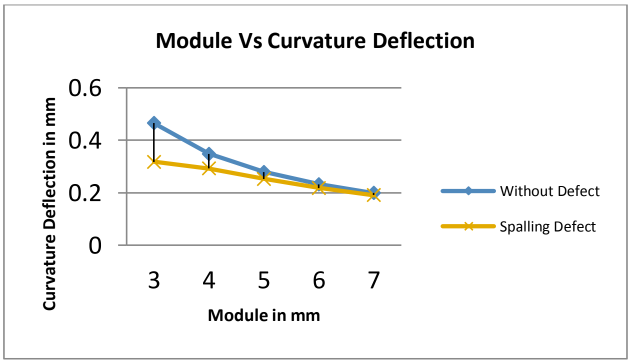

Figure 13 Graph Module Vs Curvature Deflection

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Maximum deflection is shown by the gear having no defect i.e. without defect and minimum deflection is produced in the defective gear i.e. in the gear of pitting defect when module increases.

CASE (III) - In the third case curvature deflection is shown in the form of value for healthy gear, when Pressure Angle increases. These values are showing in table 5.

Table 5 (Healthy Gear)

S.No.	Pressure Angle	Curvature Deflection (mm)
1	14.5	0.7702
2	18	0.7239
3	20	0.6972
4	24	0.6322

Figure 14 is representing the graph between the Pressure Angle and Curvature Deflection for the healthy gear.

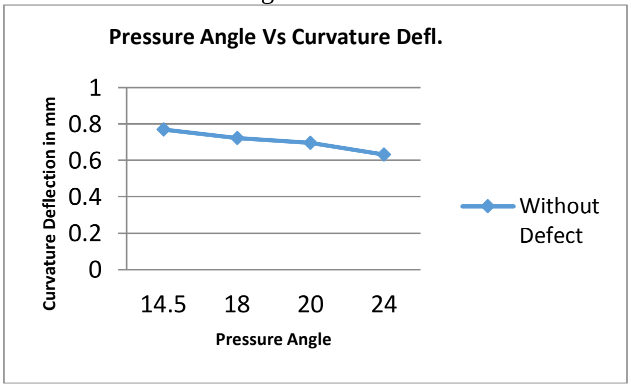

Fig. 14 Pressure Angle V/s Curvature Deflection for Healthy Gear

Now curvature deflection is shown in the form of value for defective gear like Spalling when Pressure Angle increases. These values are showing in table 6.

Table 6 (Spalling Defect)

S.No.	Pressure Angle	Curvature Deflection (mm)
1	14.5	0.2984
2	18	0.286
3	20	0.2779
4	24	0.2656

Figure 15 is representing the graph between the Pressure Angle and Curvature Deflection for the defective gear.

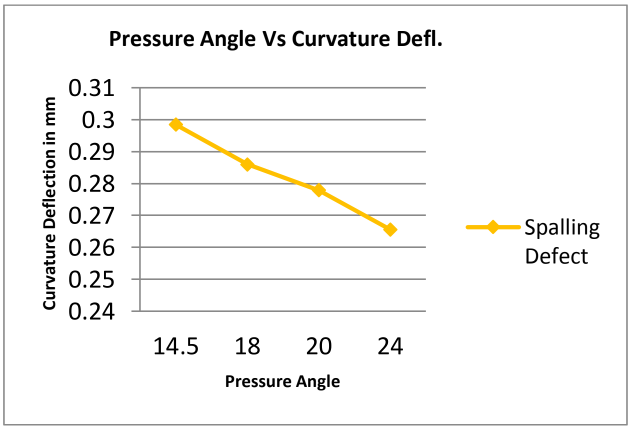

Fig. 28 Pressure Angle V/s Curvature Deflection for Spalling Defect

 ISSN: 2349- 5197
Impact Factor (PIF): 2.138

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Graph shown in the figure 16 in Case III, the effect is investigated of healthy and defective gears when different Pressure Angle; it shows the distortion produced in the gear Pressure angle of 14.5^0, 18^0, 20^0, and 24^0

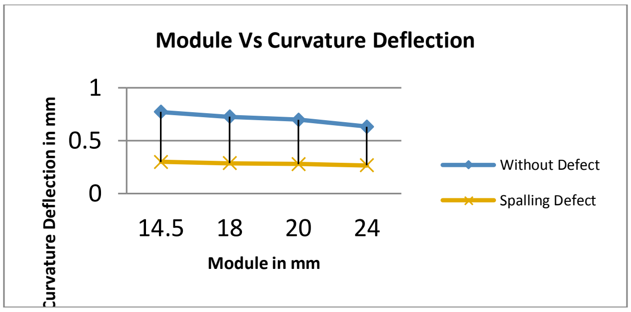

Figure 16 Graph Pressure Angle Vs Curvature Deflection

Maximum deflection is shown by the gear having no defect i.e. without defect and minimum deflection is produced in the defective gear i.e. in the gear of pitting defect when pressure angle increases.

Conclusion

The effect on the strength of involute spur gear by spalling defect was investigated. Gear of different parameters and defects but having one parameter is varied and all other parameters are kept constant was modeled and distortion produced in the curvature due to loading at the highest point of single tooth contact was analysed by finite element analysis.

1. From the analysis it is concluded that, as number of teeth increases from 15 to 30 in healthy gear curvature deflection decreases and similarly in defective gears curvature deflection decreases it is shown in figure 10. Hence we can say that when there is spalling defect in small gear then its strength will be very less compare to healthy gear but if there is spalling defect in big gear its strength will not be much lesser compare to healthy gear.
2. As module increases from 3mm to 7mm in healthy gear curvature deflection decreases and similarly in defective gears curvature deflection decreases it is shown in figure 13. Hence we can say that when there is spalling defect in gear having less module then its strength will be very less compare to healthy gear but if there is spalling defect in gear having high module its strength will not be much lesser compare to healthy gear.
3. As pressure angle increases from 14.5^0 to 24^0 in healthy gear curvature deflection decreases and similarly in defective gears curvature deflection decreases it is shown in figure 16. Hence we can say that when there is spalling defect in gear having less Pressure angle then its strength will be very less compare to healthy gear but if there is spalling defect in gear having high Pressure angle its strength will not be much lesser compare to healthy gear

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