INVESTIGATION OF METAL STIFFENERS IN FRP COMPOSITE GEARS FOR INCREASING TOOTH BENDING STRENGTH

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Abstract - In the case of Plastic (FRP)-Metal hybrid composite technology, the properties of two materials are combined in an optimal manner, resulting in synergistic effects that cannot be achieved with the respective materials alone. This hybrid composite technology has a great potential in geared transmissions where plastic-metal gears can lead to low cost, light weight, high strength & improved performance of the system. The work is intended towards enhancing the tooth bending strength of fiber reinforced plastic gears by intrusion of metal stiffeners inside the geometry of each tooth. FEA is carried out for investigation of the effect of various cross sections used for stiffener geometry and different materials used for remaining part of gear. LS-Dyna and HYPERMESH software are used for FEA study. To ensure the correctness of the results obtained by FEA, these results are correlate with available material test data.

Keywords – Metal Stiffener, Tooth bending strength.

I. INTRODUCTION

The intension of this investigation is to find out the optimum stiffener cross section & material options for Plastic (FRP)-Metal hybrid composite gear for improved tooth bending strength. Plastic gears are commonly used in today’s industry, and not only for lightly loaded applications like household appliances, tools, and toys, but also in more demanding automotive applications like electronic power steering, electronic throttle control, and starter motors.

Plastic gears are continuing to displace metal gears in a large variety of applications due it’s to various advantages compared with steel gears, such as reduced weight, self-lubrication, lower inertia, quieter running and lower manufacturing costs. However, the applications of plastic gears are limited due to a low load-carrying capacity, wear resistance and sensibility to increased temperature conditions. Therefore, reinforcement materials such as glass, carbon and aramid are added to polymer materials to overcome these obstacles to certain extent.

Previous studies on plastic gears investigated various aspects. In the 1980s Yelle and Burns conducted substantial research to give a more fundamental base to plastic gearing. In their approach they succeeded in taking into account the tooth bending of plastic gears and to calculate real contact ratios for this type of transmission. With the ongoing development of finite element software packages and improved algorithms, accompanied by sufficient computing power in the 1990s, it became possible to solve complex contact problems like meshing (plastic) gears. In the group of Walton at the University of Birmingham, the experimental research on plastic gears was combined with numerical work. They confirmed the analytical findings of Yelle and Burns by FEA and showed that load sharing changes dramatically for plastic gears. Kapelevich and co-workers used FEA to modify tooth shapes and optimize the tooth geometry specific for plastic gears.

The present study is about to enhance the tooth bending strength of fiber reinforced plastic gears by intrusion of metal stiffeners inside the geometry of each tooth. It includes studying effect of various cross sections for stiffener geometry and various materials used for remaining part of gear, on tooth bending strength and to ensure correctness of the FEA results, these results are correlates with available material test data.

II. MATERIAL TESTING

The material testing is takes place to check the correctness of the FEA results. For material testing the tensile test is performed on ISO standard specimen.

The specimen to be tested is taken as per the dimensions specified in ISO standard. The input material data is taken from actual test data converted in true stress and true strain using Mat24 LS Dyna Material format. A Database Cross Section is defined at the centre to extract the cross sectional forces. The displacement is measured at the moving end.

Fig.1 shows the tensile test specimen ad fig.2 shows the actual model on which FE analysis is carried out. In FE analysis both metal as well as plastic material specimen is tested.
III. MATERIAL SAE J2340 340XF PLASTIC STRAIN PLOT

Fig.3: Specimen Plastic Strain Plot

Fig.3 shows plastic strain plot for specimen of material SAE J2340 340XF. Similar procedure followed for material Ultramid 8272G HS BK -102 (PA6 + GF 12) and plastic strain plot.

B. Comparison of Test Vs FEA

After performing FE analysis the results are formulated in terms of stress Vs strain graph. This graph helps for getting actual difference in between test and FEA results.

Graph 1: Comparison of Test Vs FEA Results for Material SAE J2340 340XF
Graph 2: Comparison of Test Vs FEA Results for Material Ultramid 8272G HS BK -102 (PA6 + GF 12)

From the graph 1 and 2 it is concluded that the Test Data input used for Material closely correlates when the data used in Mat24 format. The difference at initial level may be due to the discretization error, round off errors, etc. which are typical errors introduced in numerical techniques.

IV. GEAR DETAILS AND FE MODEL SET-UP

A. Involute Gear of given below dimensions was used build FE model.

Fig. 4: Gear Dimensions

A. Steps For Gear Finite Element Analysis

1. Import CAD data and segregate CAD data such as gear, stiffener & shaft.
2. Discretization (meshing) of CAD domain using hexahedral & 1D elements.
3. Assign material and property to the mesh.
4. Apply boundary conditions
   a. All degrees of freedom locked at center beam.
   b. Define BOUNDARY PRESCRIBED MOTION card to describe input rotation.
5. Define Contacts between gears.
6. Define Output requests.
7. Run submission to FEA solver.
8. Interpretation of results.

B. Test Set-Up And Load Curve

The test setup is as shown in fig. 5. A deformable gear sector is chosen as test area is completed by rigid gear. It is then loaded by another rigid gear by giving incremental displacement. The load curve in fig. 6 defines input Rotation (deg) Vs Time (msec) used to rotate the driving rigid gear.

C. LS Dyna Boundary Prescribed Motion Card

The Boundary prescribed card defines the rotational input to driving gear. The above parameters are explained as below.

PID [3] - Part ID i.e ID of the driving gear.
DOF [7] - Degree of Freedom i.e input rotation about Z axis.
LCID [1] - Load Curve ID i.e. function of rotation (deg) VS Time (msec).

D. Outputs Requested

Outputs are requested by three different ways.
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i. Cross Section Forces Measurement
ii. Torque Measurement
iii. Contact Force Measurement

Three Database Cross sections are defined so as to extract the cross-sectional forces experienced by gear tooth during the test as shown in fig. 8. The centre shaft is modelled as 1D beam so as to measure torque taken by gear as shown in fig. 9. The contact force between the engaged teeth are measured as shown in fig. 10.

E. Material Data

The metal insert is of Steel SAE J2340 340 XF having yield stress 340MPa, poisson's ratio 0.3, density $7.85 \times 10^{-9}$ Tonns/mm$^3$ and Young's Modulus 210GPa. The details of the Plastic Material are given below.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Plastic Material</th>
<th>Stress (%)</th>
<th>Strain (%)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Current C/CRS-302 (PAM-GE 15) - MAT1</td>
<td>15.5</td>
<td>0.25</td>
</tr>
<tr>
<td>2</td>
<td>Current ABEC (PAM-GE 10) - MAT2</td>
<td>14.8</td>
<td>0.3</td>
</tr>
<tr>
<td>3</td>
<td>Current ABEC (PAM-GE 15) - MAT3</td>
<td>12.8</td>
<td>0.22</td>
</tr>
<tr>
<td>4</td>
<td>Current ABEC (PAM-GE 15) - MAT4</td>
<td>10.1</td>
<td>0.15</td>
</tr>
<tr>
<td>5</td>
<td>Current ABEC (PAM-GE 15) - MAT5</td>
<td>10.7</td>
<td>0.39</td>
</tr>
</tbody>
</table>

Plastic having Young's Modulus 550GPa, Poisson's ratio 0.35 and Density $1.23 \times 10^{-9}$ Tonns/mm$^3$

F. METAL INSERT PROFILE GEOMETRY

Three types of Profiles are tested.

i. Profile1: Offset involute profile
ii. Profile2: Square
iii. Profile3: Trapezoidal

G. Design Of Experiments Matrix

The following table shows design of matrix which is used for FE analysis in this work.

<table>
<thead>
<tr>
<th>Design of Experiments Matrix</th>
<th>No.1</th>
<th>No.2</th>
<th>No.3</th>
<th>No.4</th>
<th>No.5</th>
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<tbody>
<tr>
<td>Profile</td>
<td>MAT1</td>
<td>MAT2</td>
<td>MAT3</td>
<td>MAT4</td>
<td>MAT5</td>
</tr>
</tbody>
</table>

V. FEA RESULTS

A. Baseline Results (Only Metal And Only Plastic)

1. Only Metal Gear

The plastic strain and stress occurs in metal gear with respect to time is shown in following fig.

Graphs

After processing outputs are drawn from LS-Prepost for metal gear which shows in following graphs.

2. Only Plastic Gear (MAT1)

The plastic strain and stress occurs in plastic gear with respect to time is shown in following fig.
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B. Results For Design Of Experiments

Iteration P1M1

The plastic strain and stress occurs in combination of Offset involute profile (P1) metal stiffener and Ultramid 827G HS BK -102 (PA6 + GF 12) plastic material (M1) gear with respect to time is shown in following fig.

Graphs

After processing outputs are drawn from LS-Prepost for plastic gear which shows in following graphs.

Similar procedure followed for the following iterations:

After performing all iterations results are formulated and this is shown in result table.

C. Result Table

Including only metal and only plastic total 17 iterations are performed and result of this is shown in following table.

<p>| | | | |</p>
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Table 2: Result Table
CONCLUSION

1. Material testing shows that the actual test results are closely correlates with FEA results.
2. As compared to plastic gears composite gear shows better mechanical behavior.
3. Addition of metal insert increases the Torque carrying capacity substantially.
4. The combination P2M5 has highest torque carrying capacity (T = 4813.13 N-m) among all possible combinations. It is very high as compared to torque carrying capacity of plastic gear (1651.5 N-m). Square profile stiffener provides better torque carrying capacity.
5. Metal insert shape is important factor in designing composite gear and eventually deciding gear failure.
6. Proper selection of plastic material grade plays a vital role in composite gear design.

REFERENCES


