Fatigue Analysis of English-Willow Cricket Bat

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Abstract - *The design of sports equipment is an interesting task and has been evolving since decades. One such sport is cricket, a very popular game in many countries. The design of cricket bat has been evolving fascinatingly. In present age, cricket bat is made up of two different woods namely English and Kashmir willow woods. In this project it is intend to carry out fatigue analysis on cricket bat (for a defensive shot only) for English willow bat at different points on blade of the bat by applying fatigue load obtained from the different ball speeds. The actual speed of the ball at the time of impact is calculated by considering surrounding factors like pitch impact and air resistance and is used to carry out fatigue analysis. The bat is theoretically modeled, where a standard cricket bat is cross checked for its minimum cross section, then life of the bat is calculated for different fatigue load (different speed of ball) cases. The bat was then modeled accordingly in CATIA and was imported to ANSYS Workbench for fatigue analysis. Different load cases were created and fatigue analysis was carried out to predict the life of the cricket bat. Performance of the English willow cricket bat for various bowling speeds is discussed along with the weak spots.*

***Key Words*: Cricket bat, Static deflection, English willow, Life (Cycles), Finite Element Analysis (FEA)**

1. INTRODUCTION

Now a days cricket is popular game in the world. Cricket is played in three formats at the international level namely Test, One day, T-20.Test matches are of longer format (5 days), where the collision of bat and ball is maximum times in this format as compared to other formats. This repetitive load implies application of impact fatigue load on bat. Failure of cricket bat can occur much earlier due to fatigue load. In fact most of the fracture failures are initiated by fatigue loads. Cricket bat is wood product (a natural resource), hence one must use wood products in efficient way. This motivated us to determine the performance of the bat in terms of life cycle. This paper presents the details of performance evaluation of cricket bat due to impact fatigue loading by theoretical modeling and simulation in Ansys for defensive shots only. Cricket bat is made up of two main parts, handle (Cane wood) and blade (Willow wood). It is well know that the point of impact of ball and bat can be any were in the region of the bat blade. Hence we had chosen six points on the bat to study the performance with respect to impact fatigue loading. The speed of the ball is also an important factor; in our work we considered three different release ball speeds for analysis. The impact force due to three different speeds is estimated and impact fatigue load cycle is created, these load cycles are applied at six points on the bat blade and performance is evaluated. In addition a combined load cycle is created consisting of the three impact forces. This performance evaluation is carried out on cricket bat made of namely English willow. Only defensive shot is considered to reduce the complexity in performance evaluation.

2. LITERATURE REVIEW

Andre Leclereq [1] (1997) studied the quality of white willow wood along with the many other species of willow woods and found that, The scientific name of white willow is Salix alba and white willow grows up-to 25 m height like timber tree. It is given the wood of white willow has a higher impact bending strength, elasticity and a well higher rigidity (rigidity ratio: 21.5). The mechanical properties of white willow wood are studied in this paper.

Ajay K. Sarkar, et al. [2] (2011) experimentally investigated for the accelerometer profiles for sweet spot when ball hits on a cricket bat (defensive shots). Two experiments were conducted, initially the accelerometer is attached to the bat only later accelerometers are attached to both bat and hands of player. From first experiment it was noticed that minimum acceleration for impacts made in the range of 18 to 22 cm from the toe end of the bat. From second experiment it was noticed that jarring of forearm and hands will be less for sweet spot impacts. The impact spot of the bat and ball was identified by using tape, video and subject assessment methods.

V. Hariharan and **Dr. PSS. Srinivasan** [3] carried out experiment to determine the maximum ball exit velocity for various impact locations for different speed combinations of bat and ball. The combination speeds of the cricket bat and ball are 40-40 impact (40 m/s speed of the ball and 40 m/s speed of the bat), 30-30 impact, 30-40 impact and 40-30 impact. The region 0.1m to 0.17m produced maximum ball exit velocity for different above mentioned ball and bat velocity combinations. The modal analysis was carried out for the same velocity combinations. The sweet spot region was between 0.12m and 0.18m from bottom of the bat from modal analysis.

Prof. J. E. Akin, Rice University [4] studied about the impact force due to body moving with velocity or dropped from height to hit stationary beam. He made use of impact factor to calculate the impact force. If the body moving with certain velocity hits the stationary body then horizontal impact factor is used, if the body falls from certain height then vertical impact factor is used. The vertical impact factor can be applied to body moving with certain velocity horizontally and vice-versa.

Lyoyd Smith and **Harsimranjeet Singh** [5] (2008) carried out FEA as well as experimental study to know the Batted Ball Speed (BBS) with composite skin on cricket bat and without composite skin on the bat, where skin increased the BBS by 2.2%.

Cyril Okhio, Jeroen Waning and **Yemeserach T. Mekonnen** [6] (September Edition, 2011) carried out tensile, compression and bending tests to know the respective ultimate strengths of bamboo and cane materials. The ultimate strengths of cane material are studied and listed by them.

David James, et al. [7] conducted experiment on cricket bat by considering the co-efficient of restitution. The ball rebound velocity was maximum for center bat mass impacts.

It can be observed that, much of the study was carried out only on the sweet spot, modal analysis of cricket bat and batted ball exit velocity and less in regards to fatigue analysis, hence in this paper it is intended to carry out fatigue analysis of cricket bat for different ball speeds.

3. MATERIAL PROPERTIES

The English Willow, Kashmir willow and Cane wood material properties are mentioned in the below table 1.

Table -1: Material Properties

SL.No	Material	Density (Kg/ m³)	Young's Modulus (GPa)	Ultimate Impact Bending Stress (MPa)	Poisson's Ratio
1	English Willow	450	9.8	122	0.3
3	Cane	498	8.8	121	0.3

4. THEORETICAL MODELING

Using standard proportions of cricket bat [8] the dimensions of the bat are calculated. Cross section of the bat blade is non-uniform over the entire length of the bat, so minimum thickness is considered for theoretical modeling.

The minimum thickness (h) of the bat blade considered is 25 mm. The length (L) of the bat blade is 580 mm and entire length of the bat is 860mm. The length and diameter (D) of the cricket bat handle are 280 mm and 36 mm respectively. Width (B) of the bat blade is 108 mm. it is necessary to cross check the safety of cricket bat with respect to minimum thickness that is 25 mm. to cross check this the maximum ball speed is considered which is 160 KmpH at the point of release. this speed of the ball reduces at the point of impact at the bat due to air resistance and ground impact, this factor is also considered during evaluation, the details of the same are shown below.

Reduction in the velocity of ball due to air resistance is 12% of initial velocity, and after ground pitching the reduction in the velocity of ball is 30% of its initial velocity [9]. After total reduction the velocity of ball becomes 92.8 KmpH or 25.77 m/s.

Kinetic Energy of the ball $(\boldsymbol{KE}) = \frac{1}{2}\boldsymbol{m}\boldsymbol{v}_1^2$= 55.094 J

Where m= 0.163 kg and v_1 = 26 m/s

KE = Potential Energy (PE)

$$PE = m * g * H$$

55.094 = 0.163*9.81*H

H = 34.45 m.

Where H is the height from where ball is dropped to get same effect as that of ball and bat impact, which is moving with 26 m/s.

Moment of Inertia $(I) = \frac{B\,h^3}{12}$

= 1.40625 x 10^7 m^4

Static deflection $(\delta_{static}) = \frac{W\,L^3}{3\,E\,I}$

= 7.546 x 10^5 m

Where E= 9.8 * 10^9 Pa and L= 580 mm or 0.58 m

Impact factor [6] $(n) = 1 + \sqrt{1 + \frac{2H}{\delta\,(static)}}$ = 956

Impact force $(F) = n * m * g$

F = 956* 0.163* 9.81= 1528 N

Bending Moment $(M_b) = F * L$ = 8,86,240 N-mm

Where L= 580 mm

Bending stress [6] $(\sigma_b) = \frac{M_b * y}{I}$

Where y = 12.5 mm (h/2)

σ_b = 78.7 MPa

The calculated bending stress is well below the ultimate bending stress (σ_{ult}=123 MPa), so considered minimum thickness of bat blade can withstand that high impact force of the ball. Hence minimum thickness is safe.

4.1 Fatigue load spots

Impact force is calculated for different ball velocities, and that impact forces are taken as fatigue load for the fatigue analysis. For each case the same load is applied at six different spots of bat, i.e. three different points on the bat face center line and other three different points on the edge of the bat blade.

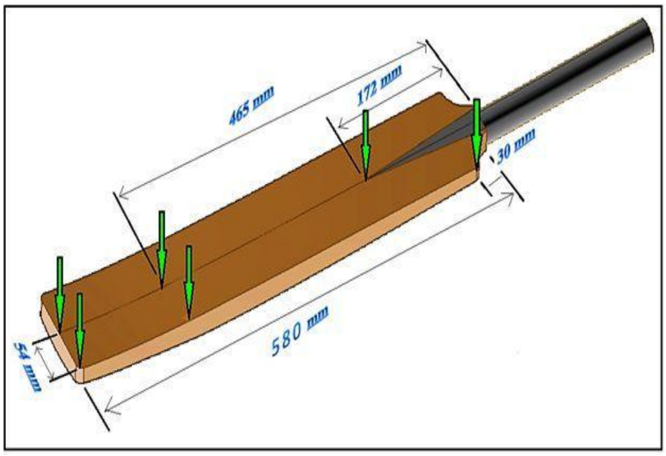

Fig -1: Load Application Spots

For simplicity the chosen spots for application of load are named as 580-Center (Toe-Center), 580-Edge (Toe-Edge), 465-Center, 465-Edge, 172-Center (V notch tip) and 30-Edge (Handle side edge). In figure 1, the distance of force applied points (spots) from fixed end are shown.

4.2 English Willow Cricket Bat case studies

4.2.1 CASE I: Ball Speed 160 KmpH

Initially bending stresses at different spots of the bat due to application of impact force are calculated, later the life of the bat with respect to obtained stress is determined. The impact force due to 26 m/s speed of the ball is 1528 N which is calculated in minimum thickness calculation. Using this force bending moment, bending stress at every spots are calculated using equations. Torsional stress and Equivalent Combined stress are calculated using respective equations and obtained values are tabulated in below table 2.

Table 1: Combined Equivalent Stress (26 m/s)

Sl. No	Force spot names	Force (F) N	Bending Moment (M_b) N-mm	Bending Stress (σ_b) MPa	Torsional Stress (τ) MPa	σ_{eq} MPa
1	580-Center	1528	886240	78.77	0	78.77
2	580-Edge	1528	886240	78.77	9.0	79.78
3	465-Center	1528	710520	63.15	0	63.15
4	465-Edge	1528	710520	63.15	9.0	64.0
5	172-Center	1528	262816	23.36	0	23.36
6	30-Edge	1528	45840	4.07	9.0	11.26

Life of English willow Cricket bat: The endurance strength of the material is one which with-stand load up to10^6 cycles. Endurance stress of the willow material is 0.3 times ultimate stress value [10]. Corrected endurance stress or fatigue strength is calculated by considering the some correction factors.

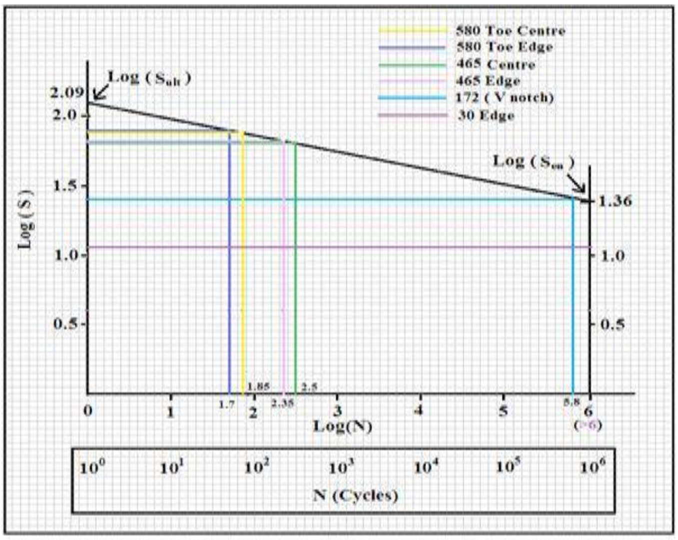

Fig -2: S-N Curve (Ball Speed 26m/s)

The factors are Size factor, load factor, Surface factor and Reliability factor. Load factor is 1 for bending and the size factor is also unity for bat. The surface of the wood will not be smooth or free from defects so Surface factor value considered is 0.9 and for reliability 90%, reliability factor 0.8 is considered.

Endurance strength (S_{en}) = Surface factor* Reliability factor * 0.3 S_{ult}

$$S_{en} = 0.9* 0.8* 0.3 * 108 = 23.32 \text{ MPa}$$

An S-N curve as shown in figure 2 is plotted for combined stress obtained in table for above mentioned various spots.

The life cycle of the bat for these spots as obtained from s-n curves is listed below in table 3.

Table 2: Life of English Cricket Bat (Ball Speed 26 m/s)

SL. No	Force spot names	Stress (S) MPa	Log(S)	Log(N)	Life Cycles
1	580-Center	78.77	1.89	1.85	70
2	580-Edge	79.78	1.90	1.7	50
3	465-Center	63.15	1.80	2.5	316
4	465-Edge	64.0	1.81	2.35	224
5	172-Center	23.36	1.4	5.8	6,30,957
6	30-Edge	11.26	1.05	>6	10^6+

Minimum life is 50 cycles at Toe edge (580-Eedge) indicating this as the weak spot. When ball hitting spot moves to-words handle the life of the bat increased.

The life cycle for two more cases that is ball speed of 130 KmpH (21 m/s) and 90 KmpH (14 m/s) respectively are estimated in similar manner as in case of 160 KmpH. The obtained life cycle are listed in below table 4.

Table 3: Life of English Willow Bat (Ball speed 21 m/s and 14 m/s)

CASES	Ball Speed (KmpH)	Force Applied Spots with Life of bat					
		580-Center	580-Edge	465-Center	465-Edge	175-Center	30-Edge
Case II	130	281	199	1995	1584	10^6 +	10^6 +
Case III	90	2,511	1,023	44,668	31,622	10^6 +	10^6 +

5. CAD MODELING

Cricket bat is modeled using CATIA V5 R20 software.

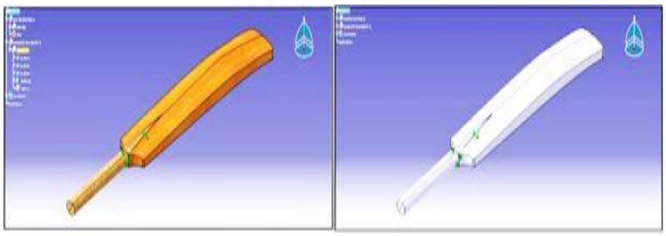

Fig -3: Assembled Bat

In figure 3, the assembled bat is shown with and without the material appearance. Assembly of bat blade and handle is done in such a way that, initially the blade is opened in the assembly section as existing component. Cricket bat handle is opened after fixing the bat blade, then mate (Contact) surfaces Constraint is given to V section surfaces and updated.

6. FEA IN ANSYS WORKBENCH

The fatigue analysis of cricket bat is carried out for defensive shots in Ansys Workbench. The CAD model is imported in Ansys workbench the material properties are updated and assigned to specific part. The contact region is specified and model is meshed. Meshing is obtained by path conforming method using tetrahedron. Meshed model is as shown in figure 4. The impact force for different speeds of ball are calculated during theoretical calculation, those forces are used for fatigue analysis under static structural tool.. In this work bat is static structural, on which impact force is applied.

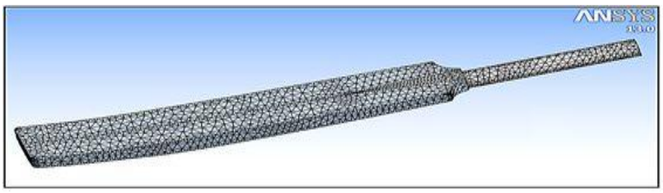

Fig -4: Meshed Model

The **Set up** command is used to insert boundary conditions like force and fixed support (Handle). In this analysis bat handle is fixed and force is applied at six spots as mentioned earlier of the bat for each case study. In **Solution** command, Fatigue tool is selected and problem is solved for the three different speeds of the ball.in FEA apart from earlier mentioned three cases, one more case (fluctuating load cycle) was considered as shown in below figure 5.

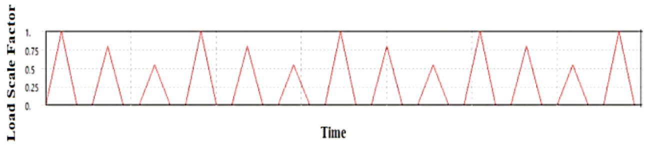

Fig -5: Non Constant Amplitude Load Cycle

All the four cases mentioned above are solved in Ansys workbench to predict the life of cycle. The obtained results are shown in below tables 5.

Life of English Willow Cricket Bat

Life of English willow cricket bat for 160 KmpH, 130 KmpH, 90 KmpH ball speed and Non constant load impacts at above mentioned six spots are listed in table 5, which are obtained from Ansys workbench.

Table 5: Life of English Willow Cricket Bat (Ansys)

CASES	Ball Speed (KmpH)	Force Applied Spots with Life of bat (cycles)					
		580-Center	580-Edge	465-Center	465-Edge	175-Center	30-Edge
Case I	160	170	140	554	357	7,20,390	9,02,400
Case II	130	345	296	2,415	1728	8,88,400	9,72,410
Case III	90	8,779	6,539	47,089	36,081	10^6 +	10^6 +
Case IV	Non Constant	151	126	503	306	6,58,640	8,62,160

The life of the English Willow bat for Non constant amplitude load (Case IV) are very less compared to constant amplitude load cases (case I, Case II, and Case III). In first three cases as speed of the ball decreased the life of the bat increased as shown in table 5.

7. RESULTS

- The life of the English-willow bat is less at toe end ball impacts, it goes on increases from toe end impacts to handle side impacts. Life of the bats depends on bending stress, bending stress is maximum at toe end and decreases along the length from toe end to handle.
- The life of the bat for edge impacts is less than same distance center impacts, because along with bending stress torsional stress is induced in the bat handle for bat edge impacts.
- The life of the bats are less for 26 m/s ball impact speed than other two ball impact speeds (21m/s and 14.5m/s).
- The life cycle pattern of ansys model is similar to that of theoretical modeling. It should be noted that a direct comparison of the results cannot be made between the theoretical and ansys model respectively, the reason being the non-uniform thickness of the cricket bat along the length of the blade. In theoretical modeling the minimum thickness (h = 25 mm) was considered, but in ansys modeling the actual varying thickness is considered. Due to consideration of actual varying thickness the life cycle for these six spots by ansys model is much higher than the theoretical modeling.
- Life of the bat for non-constant amplitude (fluctuating) load is less than 26 m/s ball impact speed because fluctuating load is more dangerous than the constant amplitude fatigue load.
- When fatigue load is applied at 172-center (V Notch), observed that failure of the bat may occur not only in the handle (fixed end) but also at the handle and blade contact region.

8. CONCLUSION

There is difference in life of the bat determined theoretically and ansys, the reason being the minimum thickness of 25 mm is considered for theoretical modeling and actual thickness is considered for FE model. The toe-edge turns to be weak spot in in the cricket bat, and this spot has to be avoided for repeated impacts. In reality the point of impact of the ball are different each and every time than the once considered in this work. Hence the actual life of the bat turns out to be higher than obtained in this work.

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