Doshisha Univ.

Development of Design System for FRP Gears for Power Transmissions

Researcher

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Introduction

Market needs

Low noise
Oil-less running
Light weight
High strength
Using for power transmission

But

Metal gear: Heavy, difficult to use oil-less condition, etc..

Plastic gear:Low loading capability, Weaker impact load.

Thus

Composite gears are attention (To meet market requirement)

Although composite gears are used in the old days, there are few researches.

In this research

Purpose: **To clearly the fundamental data for constructing a design system of composite gears.**

Using Materials

Resin → **Phenol**

Merits: Good heat-proof and impact-proof

\+

Reinforced-fibers →

1. Cotton woven cloth

Feature: Light weight, anisotropy

2. Paper

Feature: Light weight, isotropy
(Used as compared with cotton)

||

Composites

Contents of laminated composite

Material		Phenols	Cresol	25%
			Alkylphenol	25%
		Formalin		50%
Reinforced Fiber		Cotton		
Weave Type		Plain Weave		
Thickness of Cotton Yarn	[mm]	20		
Thickness of Ply	[mm]	0.25		
Fiber Concentration	[wt%]	50		

Gears

Manufacturing method

Hobbing cut

(same as metal gears)

Merits:

1. Needless injection forming.
2. Available to use metal gear manufacturing machine.

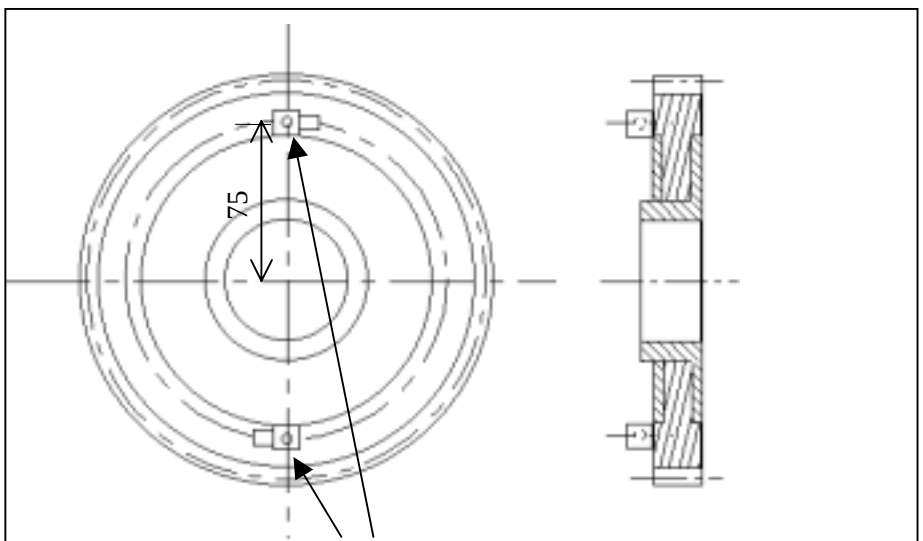
Cotton fiber-reinforced gear

Dimensions of gears

		Standard gear					Paper gear
Laminate Configuration		[0/90]s					
Module		3		4	5		4
Standard Pressure Angle	[deg]	20					
JIS Class		4					
Face Width	[mm]	25					
Tooth Depth	[mm]	6.75		9	11.25		9
Number of Teeth		49	65	49	39	49	49
Diameter of Standard Pitch Circle	[mm]	147	195	196	195	245	196
Refarence Diameter	[mm]	153	201	204	205	255	204

Running Test -1

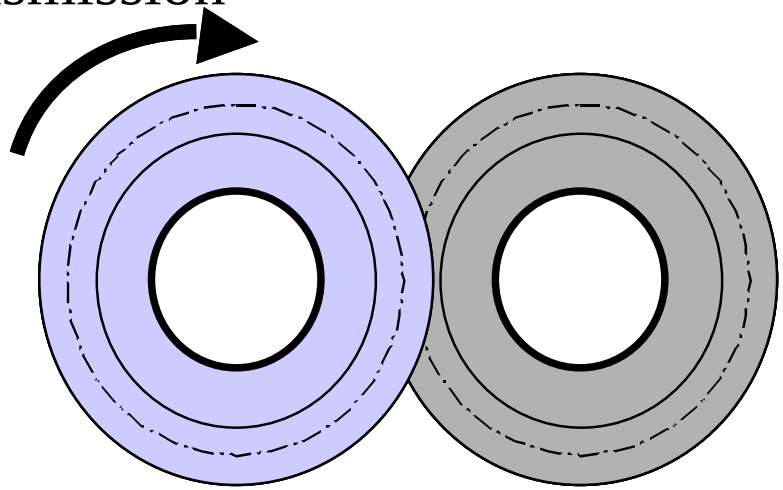
Purpose: Evaluation the possibility of mechanical factor of rotational and power transmission



Accelerometers

(To measure rotational acceleration
Under running conditions)

The method of measuring frequency



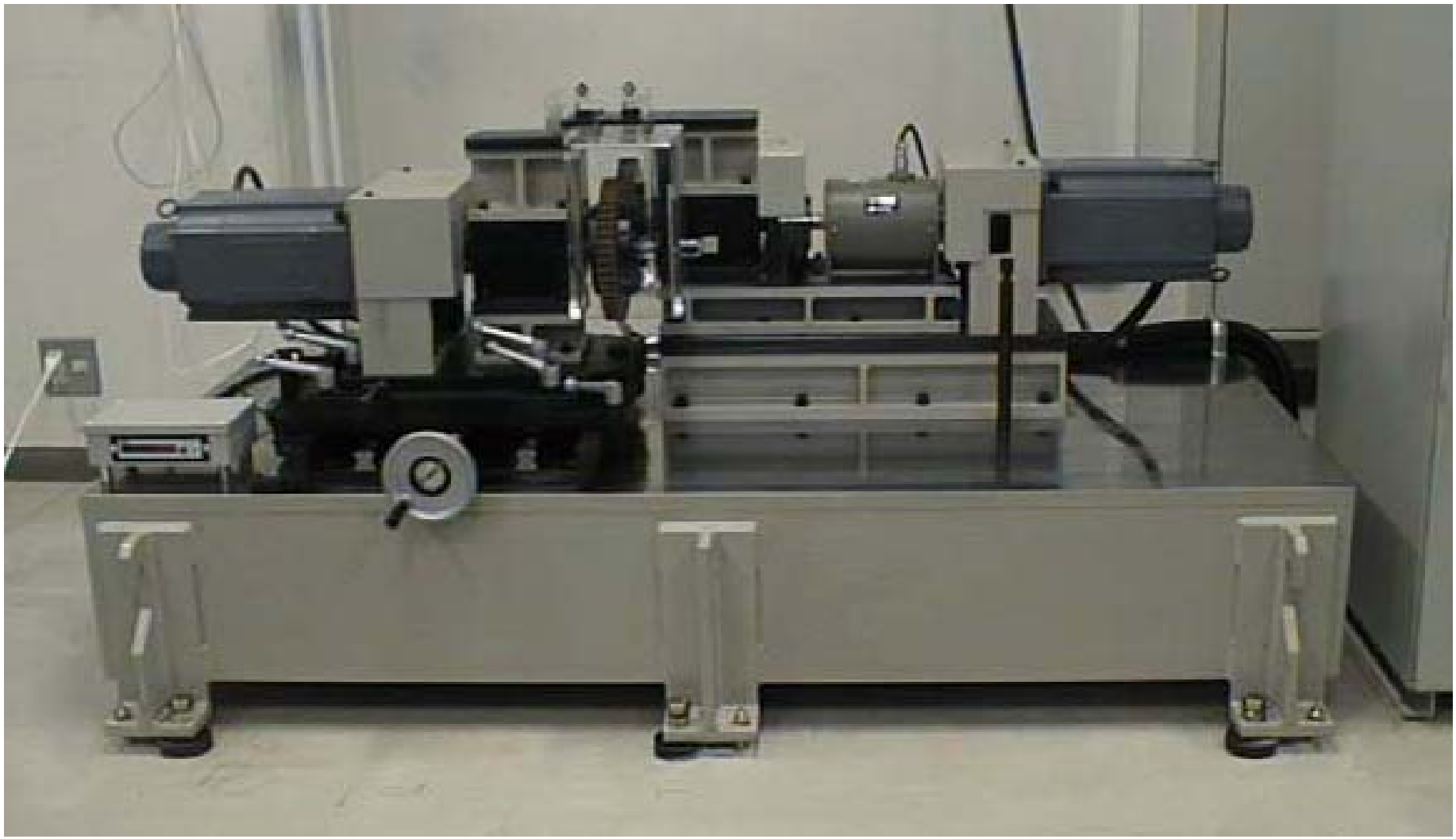
Drive gear

Driven gear

Metal gear
or
Plastic gear
(cotton fiber-reinforced)

Metal gear
(S45C steel)

Running Test -2



Running test machine

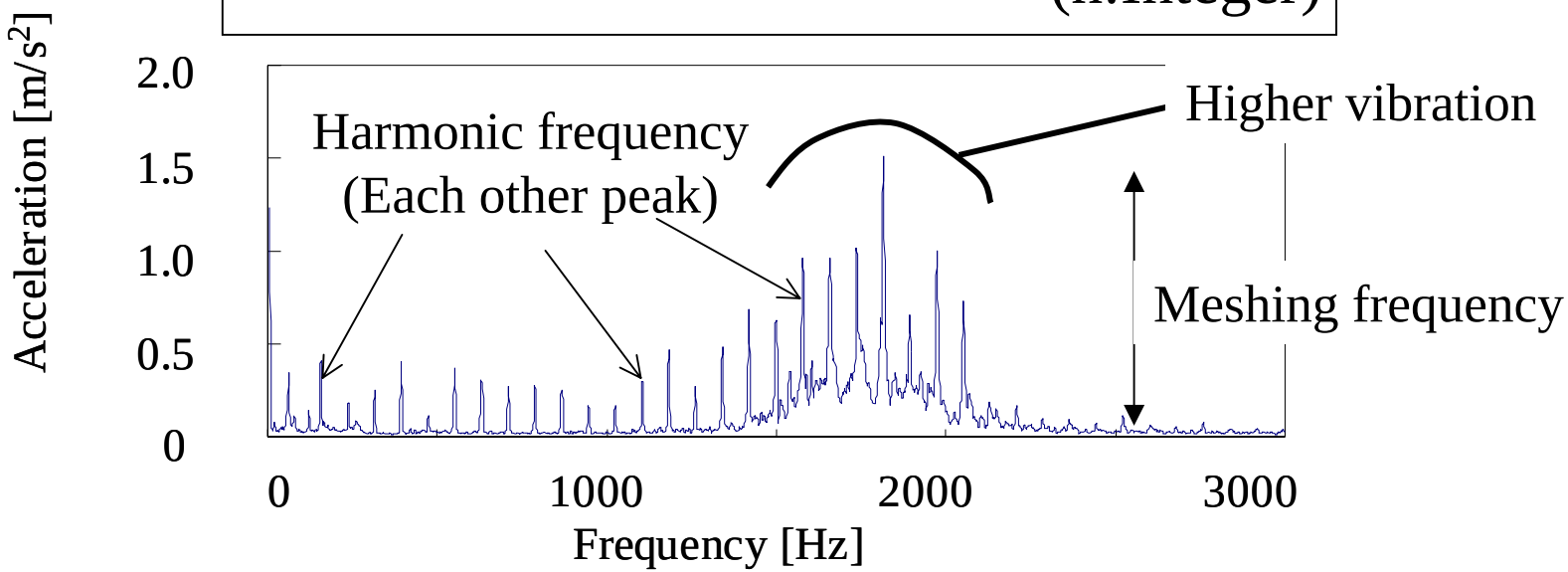
Running Test -3

View point of running test

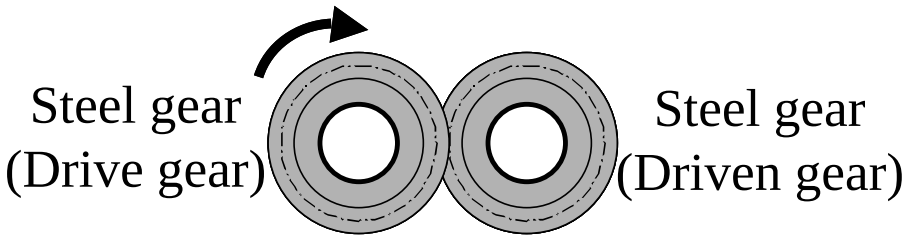
$$F_Z = Z \ N_S$$

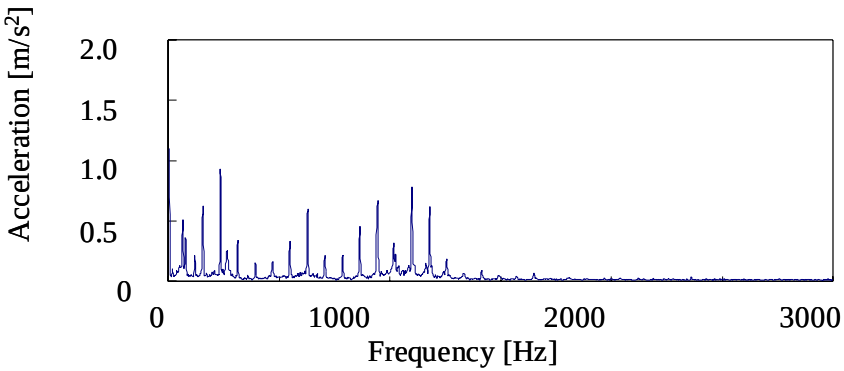
(N_S (r.p.s) = gear rotational speed
Z = The number of teeth of the rotating gear)

F_Z (Hz) =Meshing frequency
nF_Z (Hz) =Meshing frequency
(n:Integer)

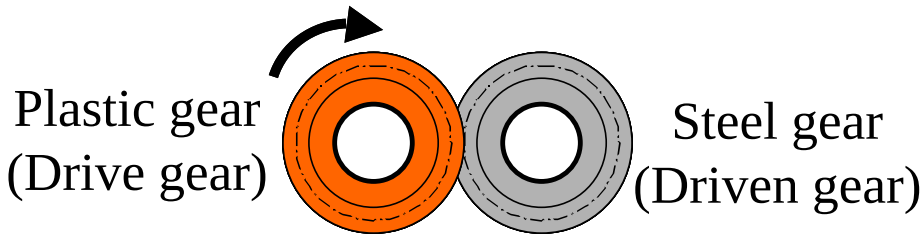


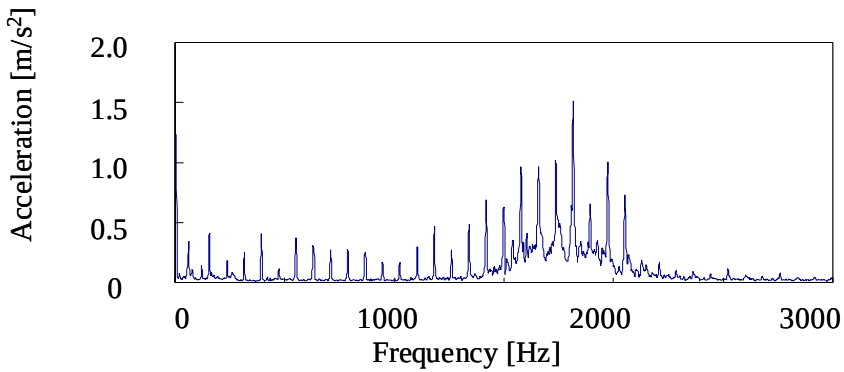
Running Test –4





Higher vibration: 300-500 (Hz)





Higher vibration: above 1000 (Hz)

<u>In this result</u>

Using elastic modulus of plastic gear → Prevent impact sound (By meshing of gear tooth)

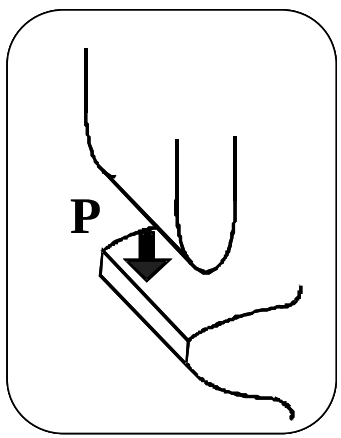
Semi-static tooth Bending Fracture Test

Purpose: To research the influence of the material anistropy on fracture modes at the loading tooth tip.

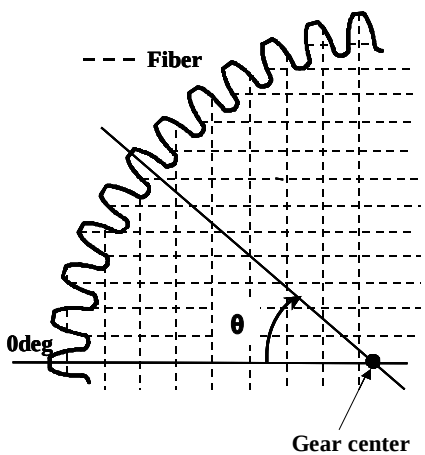
Test Condition:

Loading method → Line load at tooth tip (reference below figure)

Fiber angles of each teeth → Based on teeth of 0 degrees, and decide it within the range from 0 to 90 degrees (reference below figure)



Line load at tooth tip



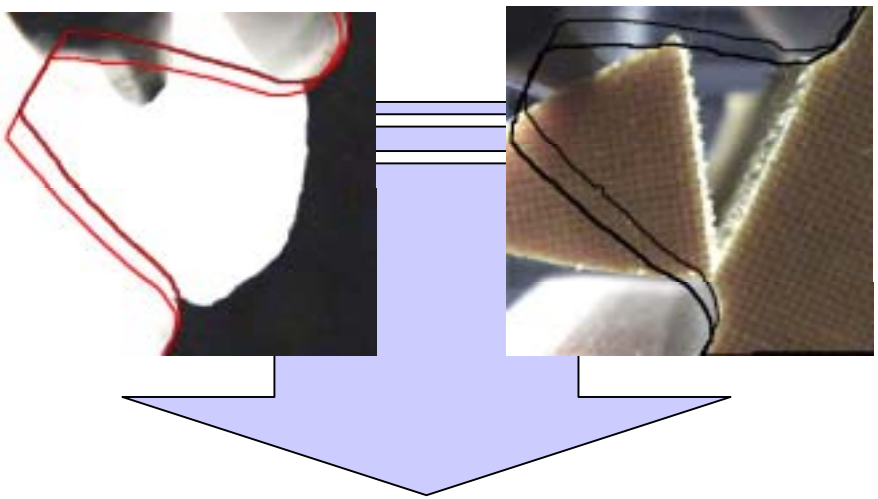
Fiber angle

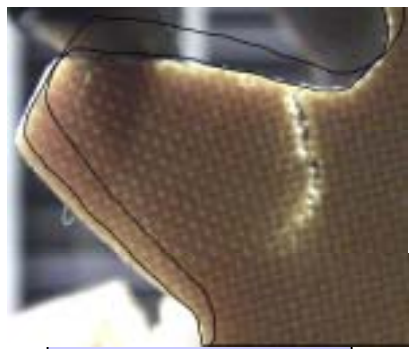
Critical cross section

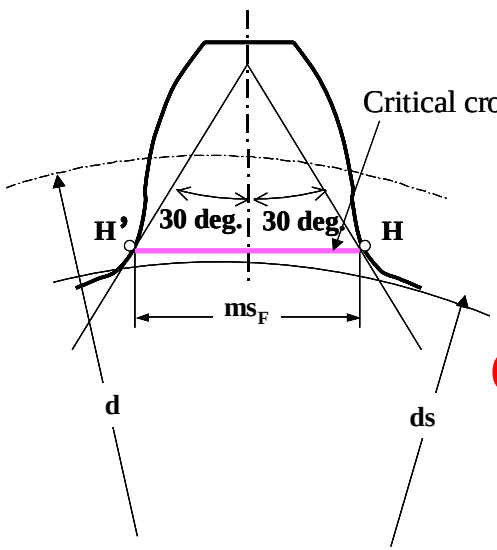
Paper reinforced

Cotton reinforced 0degree

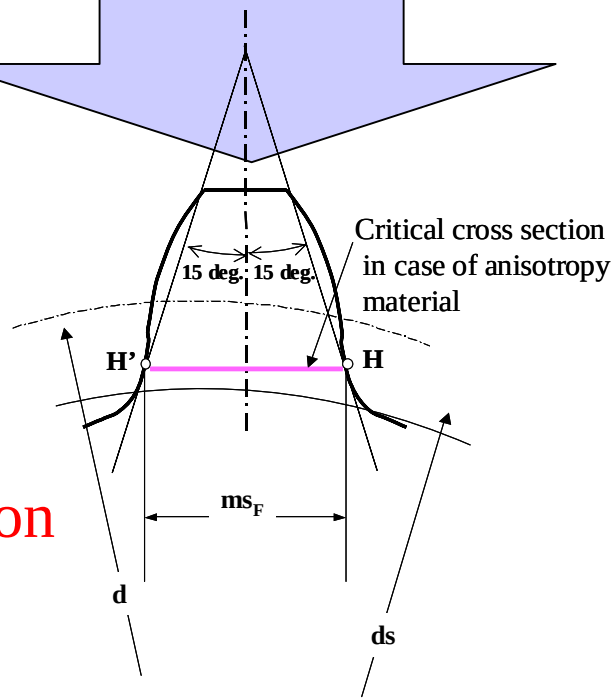
Cotton reinforced 45degrees



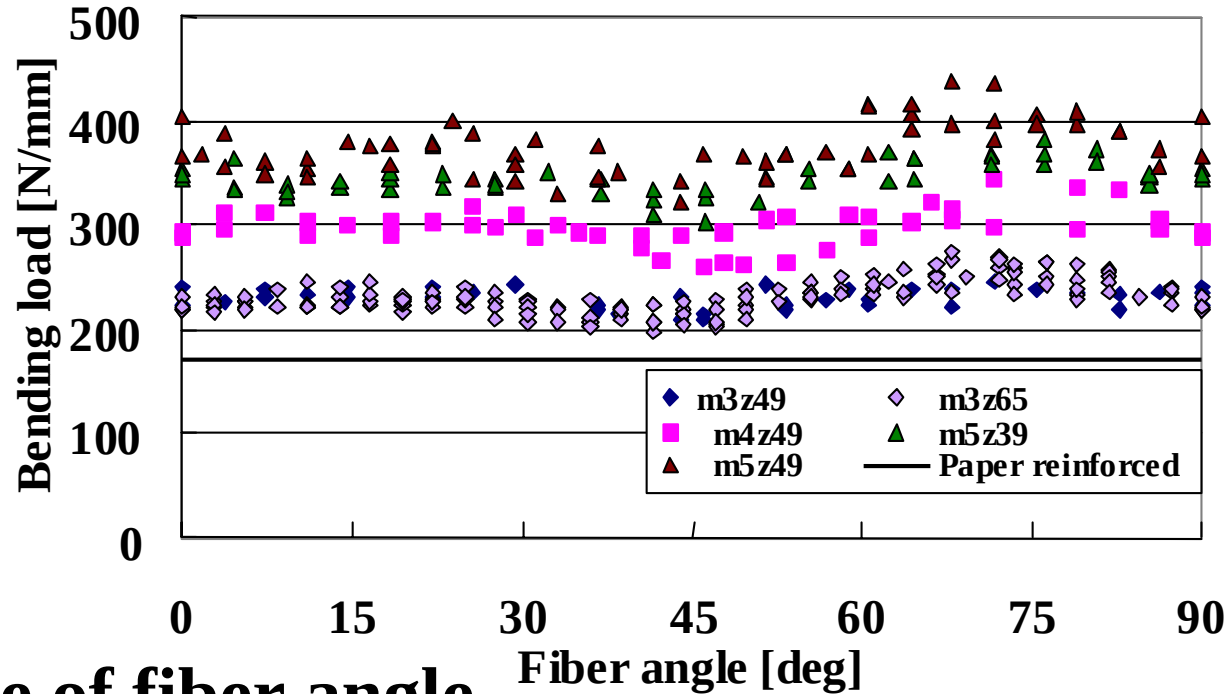




Critical cross section rise!



Bending load vs. fiber angles of teeth



Influence of fiber angle

45degrees gear tooth is weakened!

Teeth strength

Cotton fiber-reinforced gear > **Paper reinforced gear**

Material Tests

Load to tooth tip

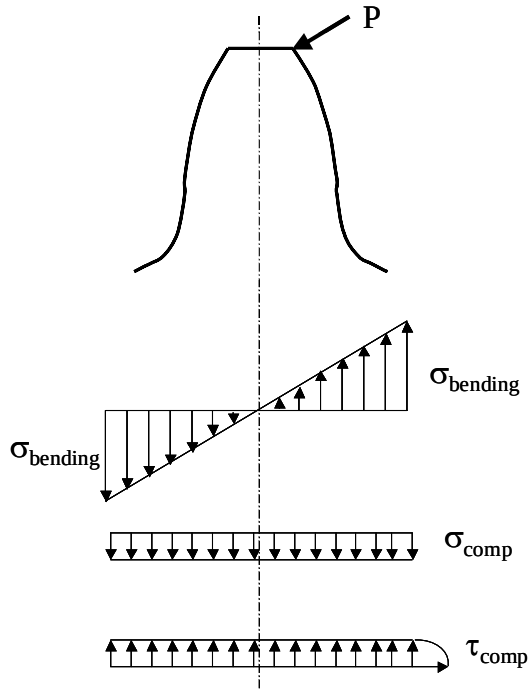
Tensile, Compressive, Bending, and Shearing stresses
are risen in tooth root
(As shown in right figure)

Thus

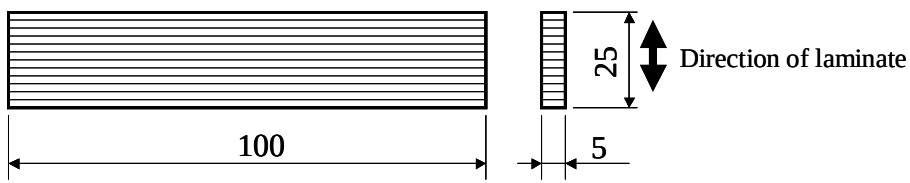
Various material tests

Comparison

Bending fracture test



Tooth tip load



Shape of specimen

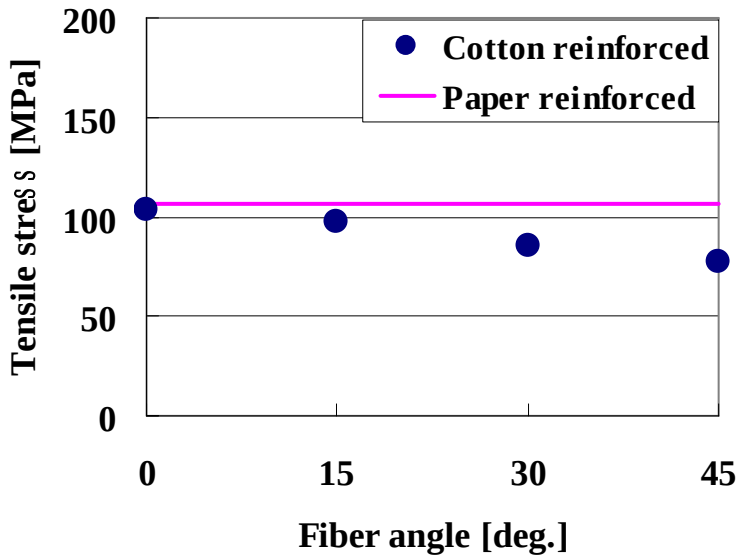
Tensile Test

Purpose: To research most basic material properties.

Influence of fiber angle

Cotton Reinforced

Few influence



Result of tensile test

Tendency of Strength

Tensile test			Bending fracture test		
Cotton reinforced	<	Paper reinforced	Cotton reinforced	>	Paper reinforced

Not same tendency!

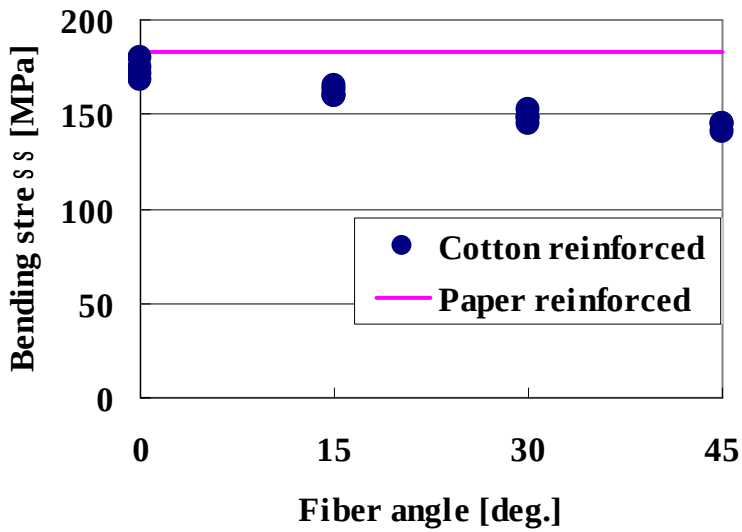
Bending Test (3 point bending)

Purpose: To research Bending strength of materials.

Influence of fiber angle

Cotton reinforced

Few influence



Result of 3-point bending test

Tendency of strength

3 point bending test

Cotton reinforced 〈 Paper reinforced

Bending fracture test

Cotton reinforced 〉 Paper reinforced

Not same tendency!

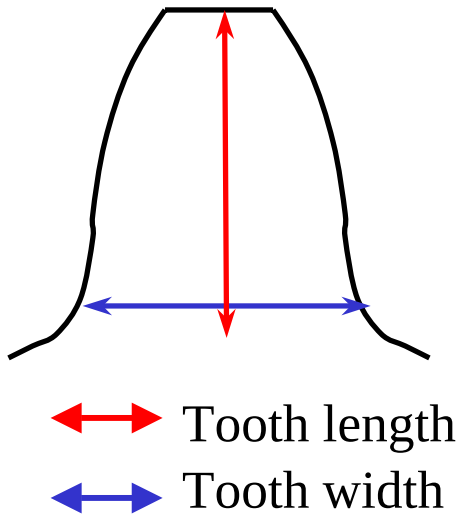
Shearing Test

Width of tooth is wide compared with tooth length
(As shown in Figure)

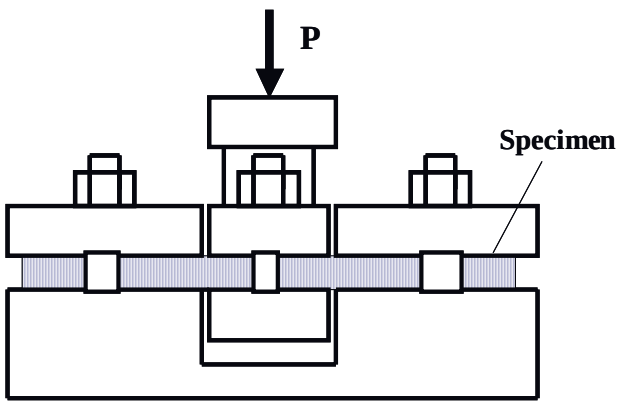
So

Shearing force can’t ignore !

Thus



Conduct a shearing force investigation



Shearing test tool

Shearing Test

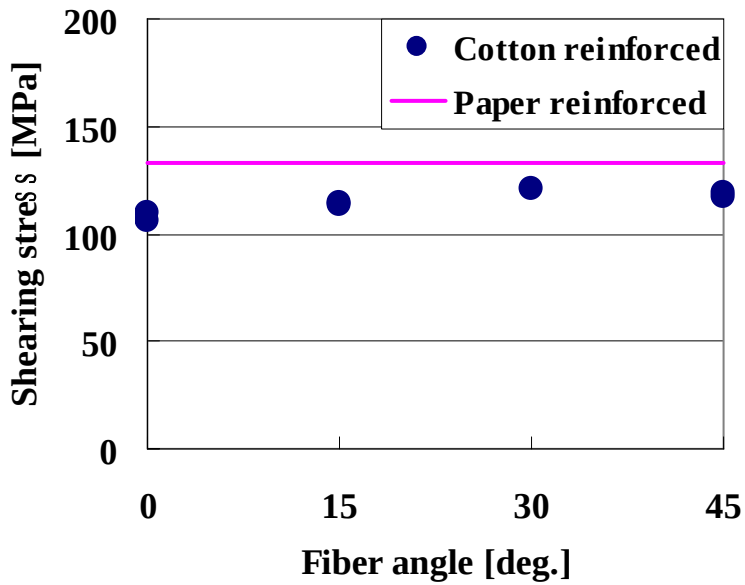
Purpose: To research shear strength of materials.

Influence of fiber angle

Cotton Reinforced

Hardly influence

(Need to more research)



Result of shearing test

Tendency of strength

Shearing test

Cotton reinforced $\doteqdot$ Paper reinforced

$\Leftrightarrow$

Bending fracture test

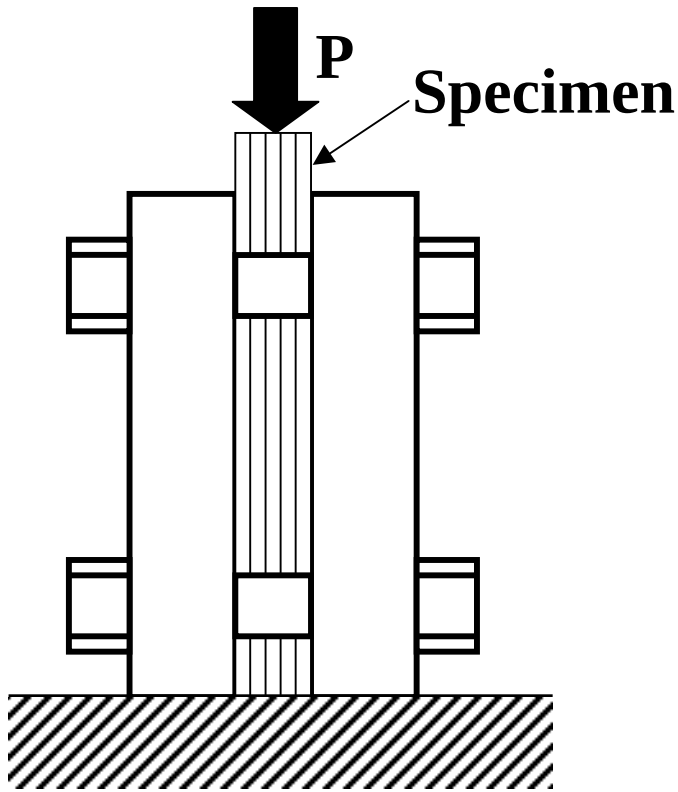
Cotton reinforced $>$ Paper reinforced

Not same tendency!

Compressive Test -1

Using Tool to stability specimen for prevent buckling, as shown in below figure.

Compressive test tool



Compressive test

Compressive Test -2

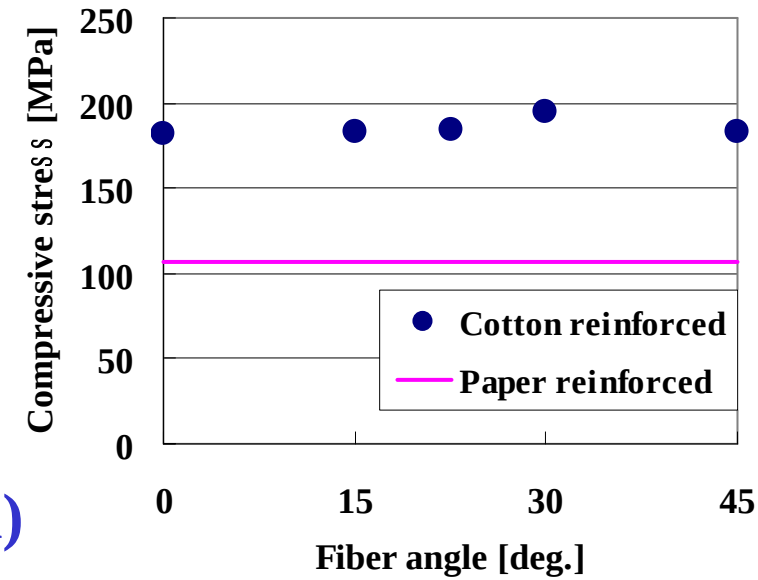
Purpose: To research compressive strength of materials.

Influence of fiber angle

Cotton Reinforced

Hardly influence

(Need to more research forward)



Result of Compressive test

Tendency of strength

Shearing test

Cotton reinforced 〉 Paper reinforced

⟺

Bending fracture test

Cotton reinforced 〉 Paper reinforced

Same tendency!

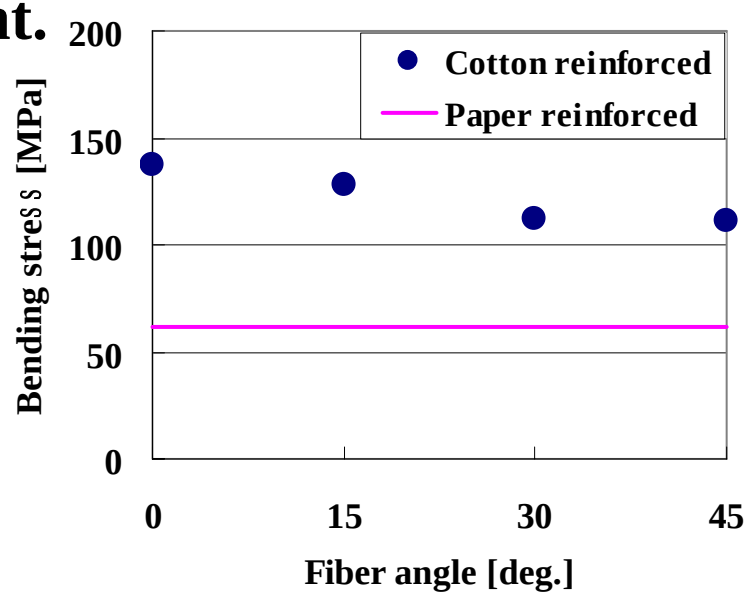
Bending Test (4 point bending)

Purpose: To research Bending strength of material only for pure bending moment.

Influence of fiber angle

Cotton reinforced

Few influence



Result of 4-point bending test

Tendency of strength

3 point bending test

Cotton reinforced 〉 Paper reinforced

⟺

Bending fracture test

Cotton reinforced 〉 Paper reinforced

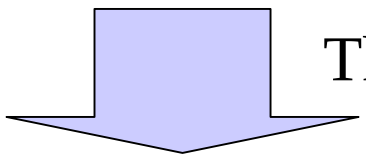
Same tendency!

Method for Estimating Tooth Root Stress

From result of tooth bending fracture test

Critical cross sections are risen

(We thought there are greatly influenced by shear stresses,
because of the shearing stresses rises by going to the points of teeth.)



Thus

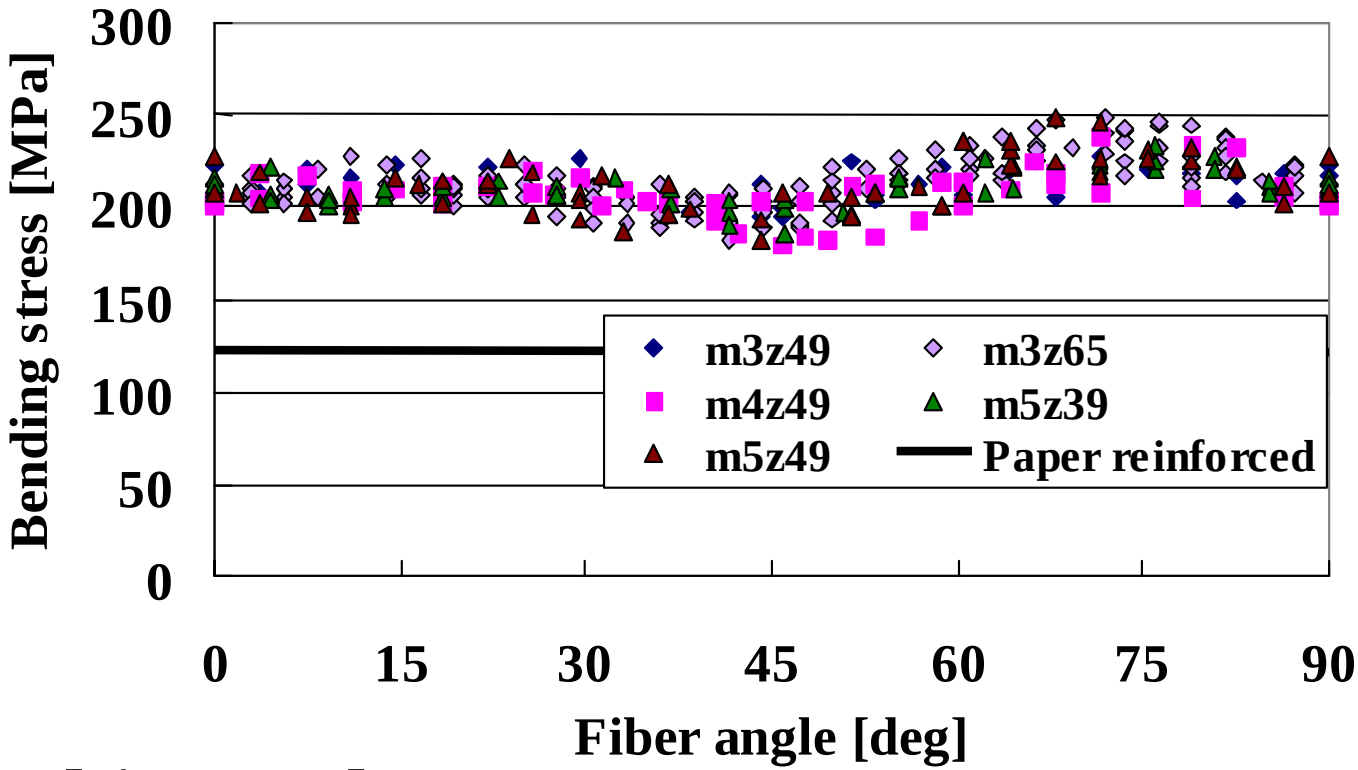
The tooth root stress type of anisotropic material to consideration of the influence of the shearing strength

$$Se = \sqrt{(Sn)^2 + (2.5Tn)^2}$$

(*Se* = equivalent stress
Sn = Vertial stress
(when loading the tip)
Tn = the shear stress
(when loading the tip))

This function apply tooth root stress…..

Method for Estimating Tooth Root Stress



In this result

Without tooth module

Available to estimate the tooth root strength!

Fatigue Test -1

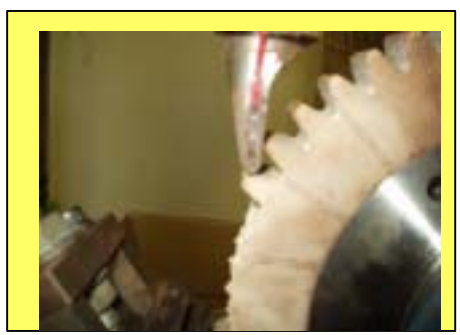
Purpose: To research frequency until tooth broken under constant load and loading cycle.

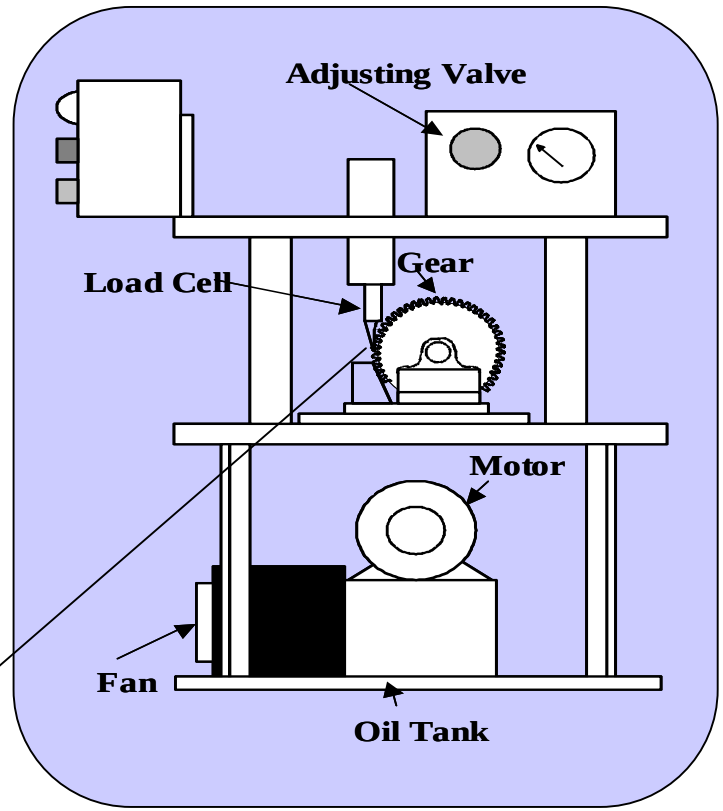
Test condition:

Load cycle → 100/min (1.7Hz)

Loading method → Line load to Tooth tip (Same as bending fracture test)

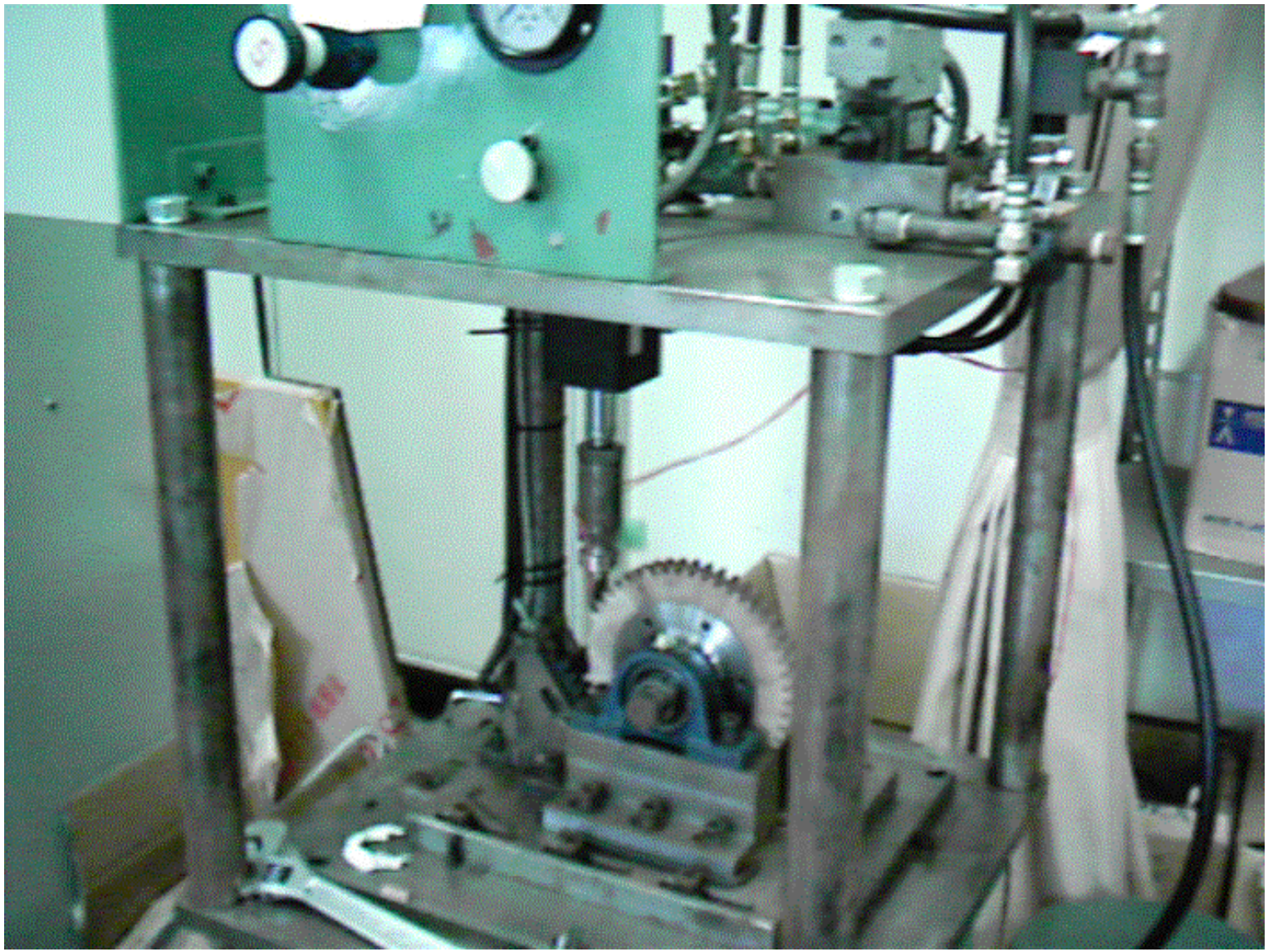
Object tooth → 45 degrees tooth (Weaken tooth)



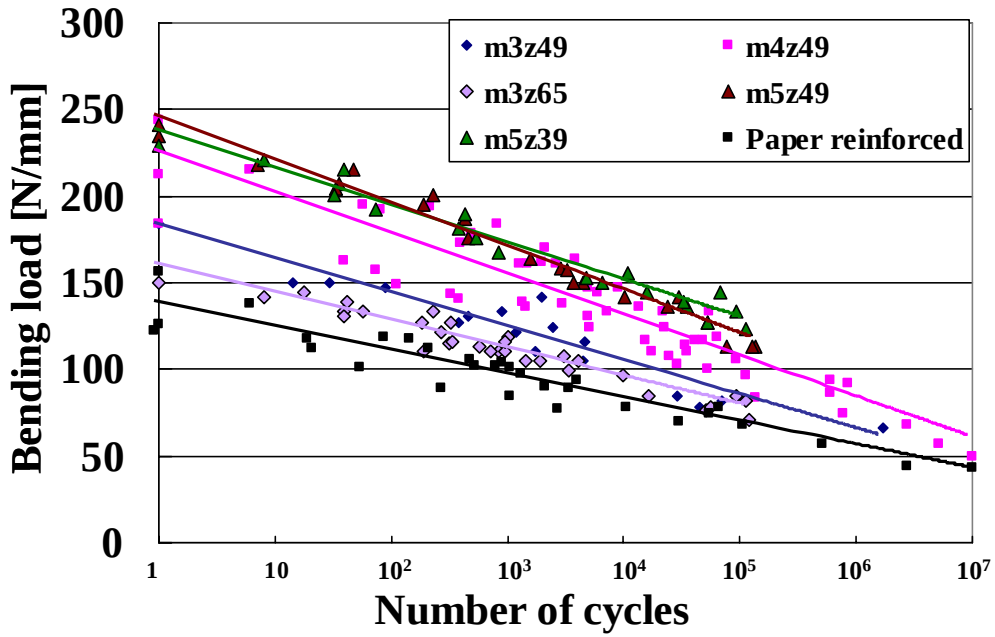


Fatigue test machine

Fatigue Test -2



Fatigue Test -3



Result of fatigue test

Strength tendency

Cotton fiber-reinforced gear 〉 Paper reinforced gear

More than 100 times in same load!

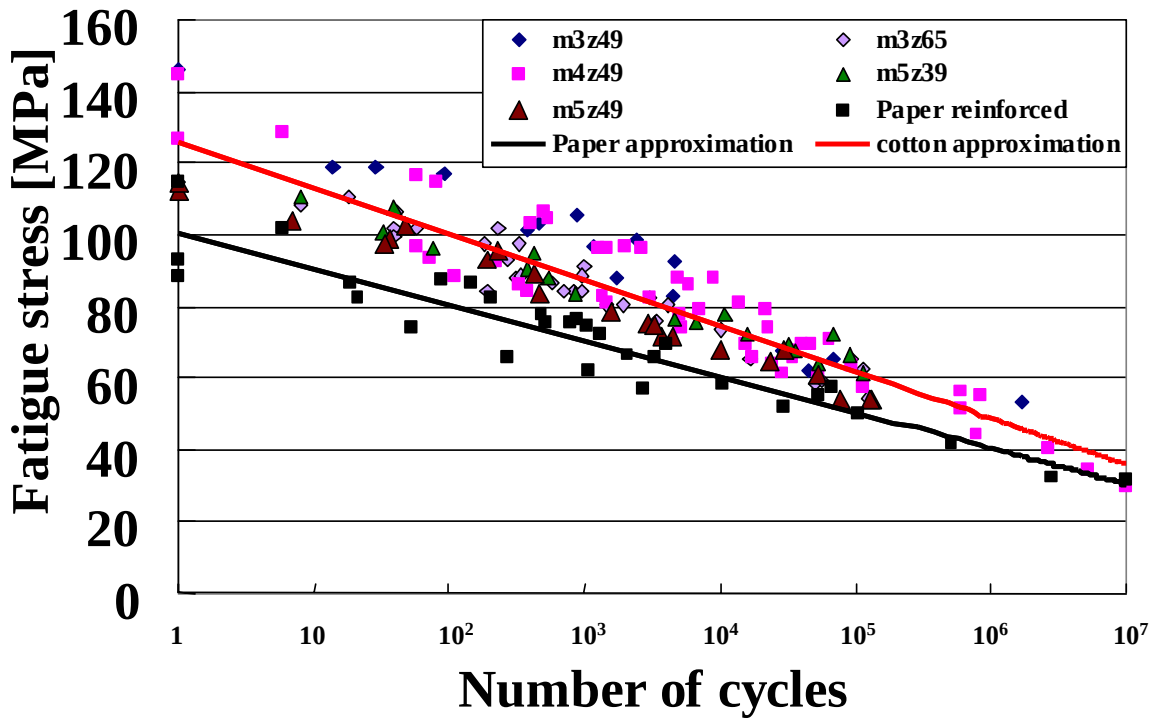
And

Apply below function in above result……

$$Se = \sqrt{(Sn)^2 + (2.5Tn)^2}$$

(Se = equivalent stress
Sn = Vertial stress
Tn = the shear stress)

Fatigue Test -4



Result of fatigue test

In this result

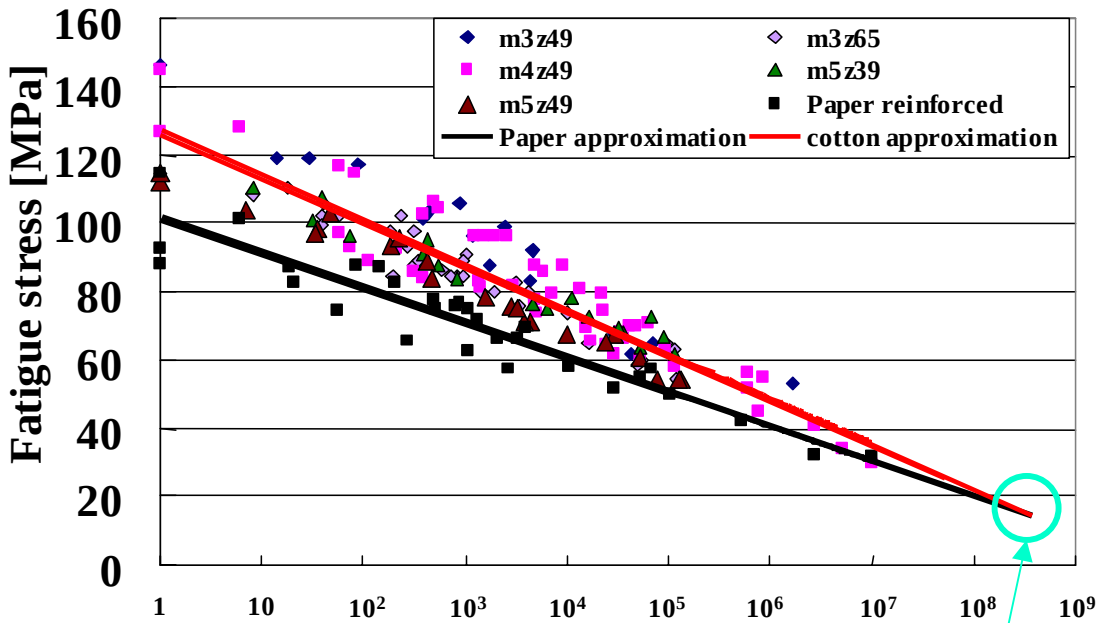
Capable to estimate by the stress!

(Regardless of the module)

And

Extension each approximation lines……

Fatigue Test -5



Result of fatigue test

In this result

Approximation lines cross in one point

Small load → **Fatigue strength depends on resin strength!**
(Regardless of reinforced fiber)

Results

1. It is confirmed that better noise quality, which avoids unpleasant-sounding frequencies in the field of human engineering, is obtained using plastic gears made of cotton fiber-reinforced phenolic resin in operating machines.

2. With a cotton cloth-reinforced plastic gear, the strength of a tooth with a fiber-reinforcement angle of 45 degrees is lowest when the load is applied to the tooth tip. The fracture occurs from the tooth root fillet on the tooth tip side, which is a critical tangency point of a 15-degree angle.

3. There are same tendency of strength between Compressive, 4-points bending and gear bending strength made of phenolic resin.

4. As a result, it is necessary to input the basic material data of the tensile, bending and shear strength of the cotton cloth-reinforced plastic laminates at the fiber reinforcement angle of 45 degrees in order to estimate the tooth root stresses. It is also necessary to consider the stress concentration factor of the tooth root fillet in design systems.

5. The fatigue strength of cotton fiber reinforced gears is 100 times that of paper-reinforced gears.

6. Fatigue strength depends on the strength of the resin regardless of the strength of a reinforced fiber when the load is small.