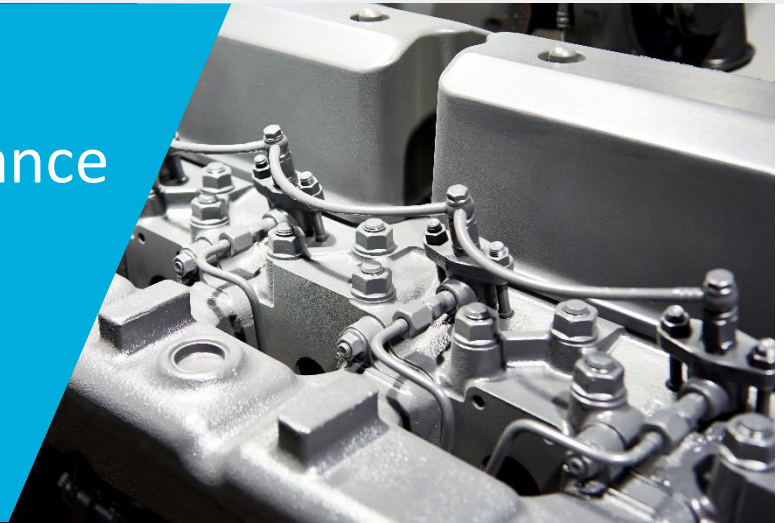


CASE STUDY

# Reduce Warpage, Enhance Strength & Modulus, and Reduce Costs with Flat Glass Fibers



## Summary

**Product type:** Chopped strand glass fiber with oval cross-sectional shape

**Application:** Automotive, aerospace, marine, construction, sports goods, chemical processing equipment and civil infrastructure

**Key benefits:** Low warpage | Good dimensional stability | Higher strength & modulus | Reduced deformation | Cost Reduction

## The Challenge

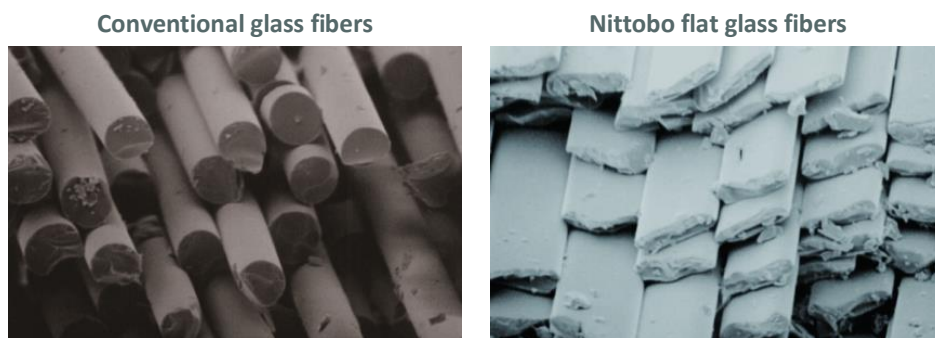
Fiber-reinforced Plastics (FRP) is a composite material made of a polymer matrix reinforced with fibers. The most used fibers are made of glass, aramid or carbon while the matrix is generally made from thermo plastic polymers, such as Polypropylene, Polyamide, Polyester or other engineering plastics. The use of FRP composites continues to grow at an impressive rate. The composite material is replacing metals and alloys in applications that require heat and chemical resistance with high material strength. FRPs offers the benefits of noncorroding, lightweight construction with strength and stiffness that can be tailored to meet the specific performance requirements.

In the automobile industry, transition to electric vehicles (EV), and increasingly stringent legislation regulating fuel economy, are driving car manufacturers to replace metal parts with lighter FRPs. While low performance automotive parts have been easy to replace, metal parts that are subjected to extreme conditions during operation still pose challenges. For example, the cylinder head cover is subjected to extremely high temperatures and aggressive chemicals. While FRPs can be engineered to endure these extreme conditions, the replacement of metals with FRPs has proven challenging due to the issue of warpage. In injection molding, warpage is the twisting, bending or bowing of the molded part which causes the shape to distort and deviate from design specifications. Warpage is generated due to non-uniform shrinkage during injection process, especially the molding process. It can lead to residual stress in FRP parts and may cause oil leakage if not sufficiently reduced in critical engine parts,

such as the cylinder head cover. The challenge, therefore, is to reduce warping in molded FRP parts allowing the benefits of lighter weight composites to be fully exploited.

## The Solution

Glass fiber is an inorganic fiber widely used in FRP for its strength, resistance to heat and chemicals, nonflammability, and electrical insulation properties. Nittobo offers a range of chopped glass fiber strands with a modified cross section. These flat fibers (FF) are produced using Nittobo's proprietary technology. Nittobo flat fibers have an oval cross section in contrast with conventional fibers that are cylindrical, with a circular cross-section (Figure 1). Due to their unique shape, Nittobo flat fibers exhibit some very useful characteristics when used as a base material for injection molding. These advantages include low warpage, enhanced tensile strength, and greater dimensional stability. Suitable for use with Polypropylene, Polyamide, ABS, PPS and other super engineering plastics, Nittobo flat glass fibers find applications in a range of industries.



*Figure 1: Nittobo flat glass fibers have an oval cross-section*

In high-performance engines, cylinder head covers made with aluminum are being replaced with those made from glass fiber reinforced polyamide, to reduce the weight of the vehicle. FRP covers tend to show significantly large warpage; the resulting distortion can cause oil leakage and may lead to residual stress. A simulation study was carried out to investigate if warpage can be reduced by replacing conventional glass fibers with Nittobo flat fibers in the production of a cylinder head cover. Figure 2 shows the simulation model of the head cover and the locations that are most affected by warpage. The analysis was carried out using AUTODESK Moldflow®. Moldflow® is a simulation software used to troubleshoot problems with plastic injection molding. The software tools help identify and solve manufacturing challenges, such as warpage and cooling efficiency.



Figure 2: Simulation model of a cylinder head cover showing warpage locations

Two types of Nittobo flat fibers were chosen for the study: CSG 3PL-820 and CSG 3PA-820. Both fibers have a cutting length of 3mm and a moisture content of less than 0.1%. CSG 3PL-820 fibers have an average flat ratio of 2 while CSG 3PA-820 fibers have an average flat ratio of 4. The flat ratio is defined as the ratio of the length of the major axis to the length of the minor axis of the oval cross section. Table 1 shows the key properties of the two Nittobo fibers. A conventional glass fiber, with a circular cross section (flat ratio= 1) was used as a reference.

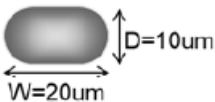
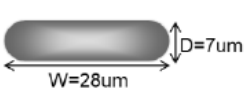
Property	Units	CSG 3PL-820 Flat fiber	CSG 3PA-820 Flat fiber
Flat ratio (Average)	-	2	4
Cutting length	mm	3	3
Moisture content	wt. %	<0.1	<0.1
Loss of Ignition	wt. %	0.50	0.50
Cross-sectional shape			

Table 1: Key properties of Nittobo glass fibers used in the study

## Reduced Warpage

Figure 3 shows the fill time analysis result of the cylinder head cover model. The contour colors depict the flow of plastic into the mold; similar colored regions are filled simultaneously. The dark blue region is filled first at the start of the injection process, and red areas are the last to fill up.

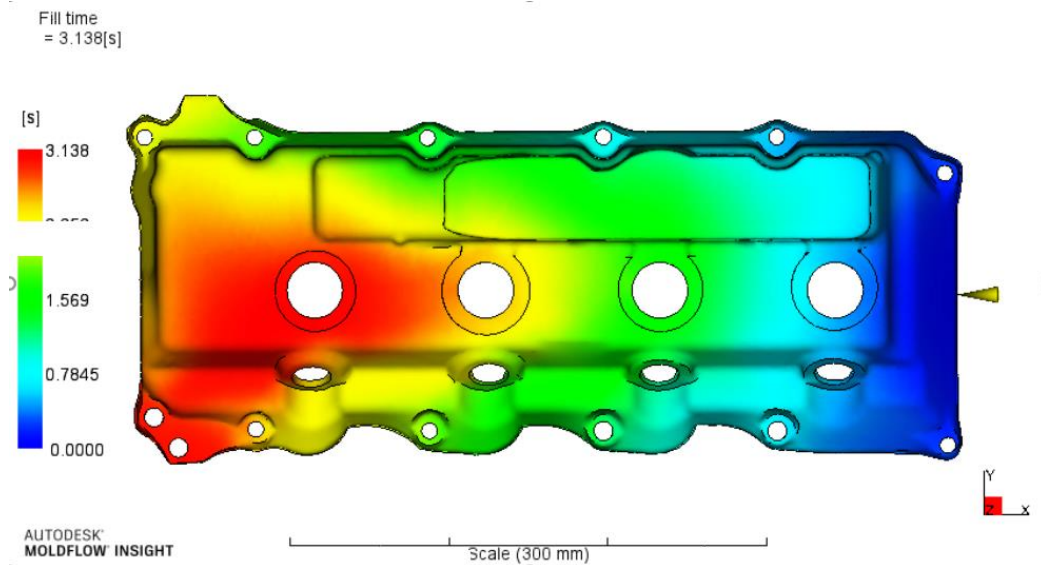


Figure 3: Fill time analysis of the cylinder head cover model. The plastic flows in from the right and fills towards the left.

Figure 4 shows the fiber orientation tensor result for the model at the end of the injection molding process using glass fiber. This result shows the probability of fiber alignment in a specified direction. The direction in which most fibers align is called the principal direction. A value close to 1 indicates a high probability of fiber alignment is in this direction. Comparison of Figures 3 and 4 shows that the fibers are aligned in the injection flow direction creating anisotropy. The anisotropic nature of a fiber filled material causes uneven shrinkage as the material is stiffer in the fiber direction. The variation in shrinkage across the molded part leads to warpage.

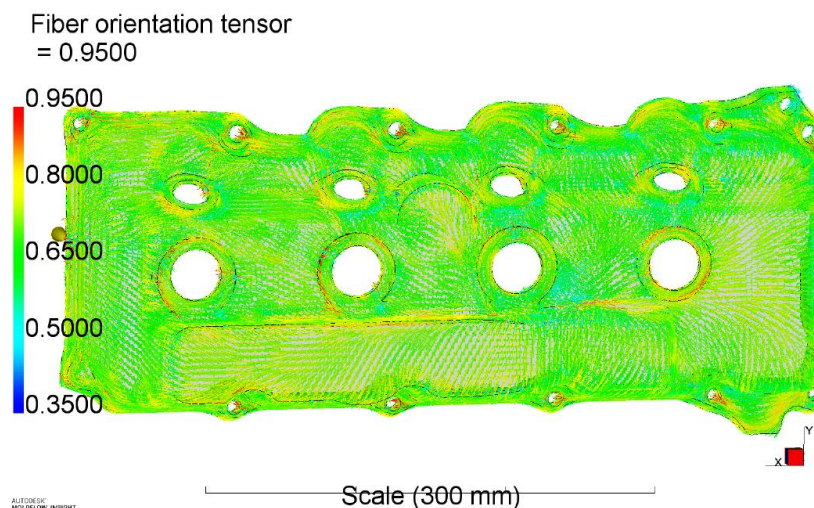


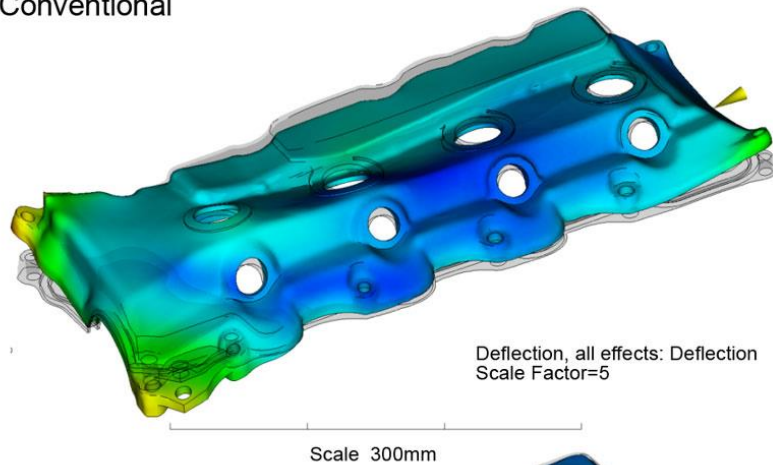
Figure 4: Fiber orientation result of the engine cover

Figure 5 shows the comparative warpage analysis results of a cylinder head cover, injected from the side gate of the mold. The dark blue regions indicate no warpage whereas the yellow region indicates warpage of around 7mm. The results for conventional fiber glass show the greatest warpage. The warpage is maximum at the corners of the molded part. The Nittobo flat fiber glass with a flat ratio of 2 (CSG 3PL-820) shows significantly less warpage. The warpage is minimum for the part molded with Nittobo flat fiber glass with a flat ratio of 4 (CSG 3PA-820). Figure 6 shows the comparative warpage

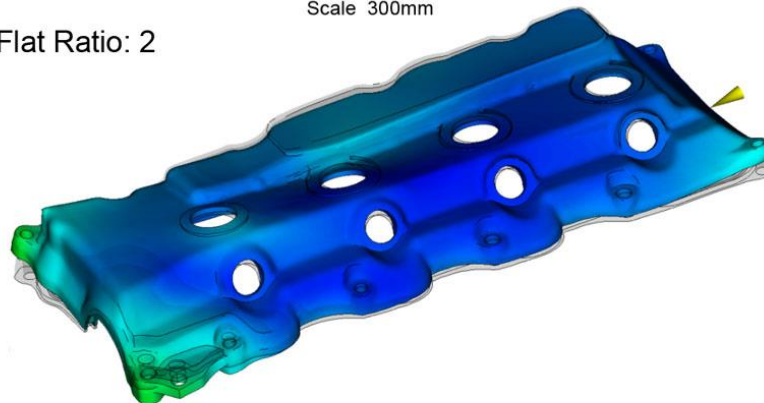
analysis of the same part produced with center double gate injection. The results are very similar with Nittobo flat fibers showing significantly less warpage.

The warpage simulation results show that Nittobo fibers with a flat ratio of 4 (4FF) perform better than fibers with a flat ratio of 2 (2FF). The results also indicate that the use of flat fibers significantly reduce warpage irrespective of the position and number of injection gates. The orientation of flat fibers in molded parts is less anisotropic which leads to more even shrinkage and causes less warping or twisting in the final product.

### Conventional



### Flat Ratio: 2



### Flat Ratio: 4

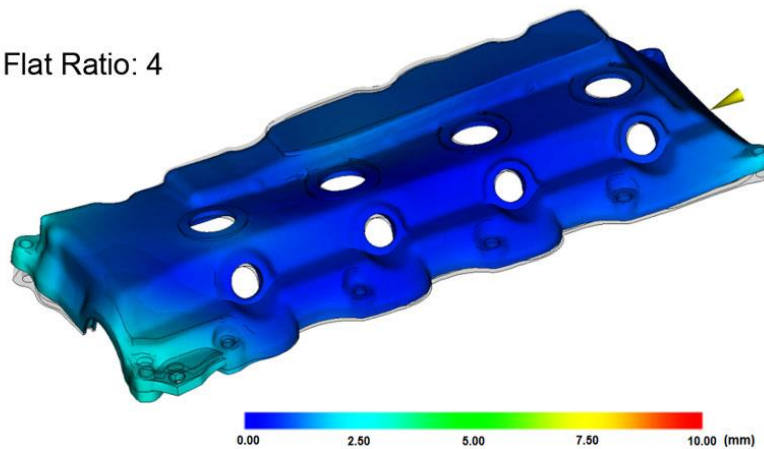
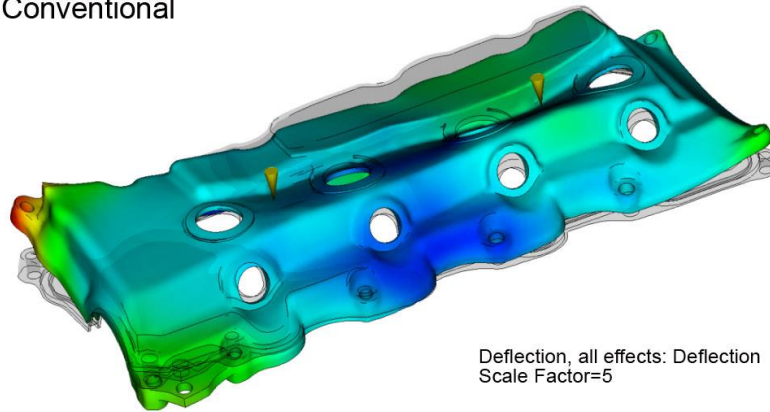


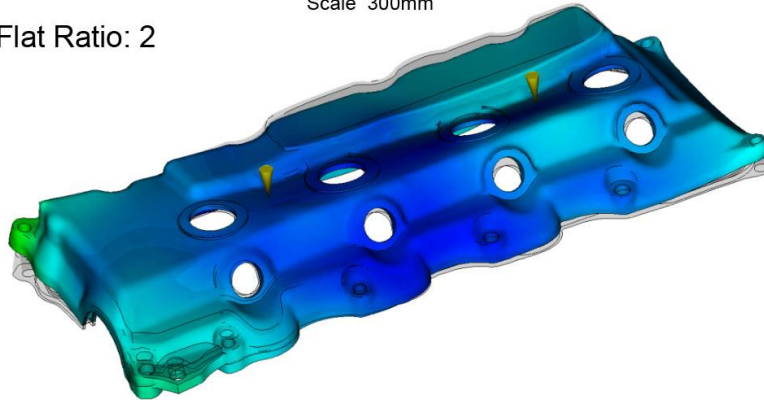
Figure 5: Comparative warpage analysis of the cylinder head cover injected from the side gate

Conventional



Scale 300mm

Flat Ratio: 2



Flat Ratio: 4

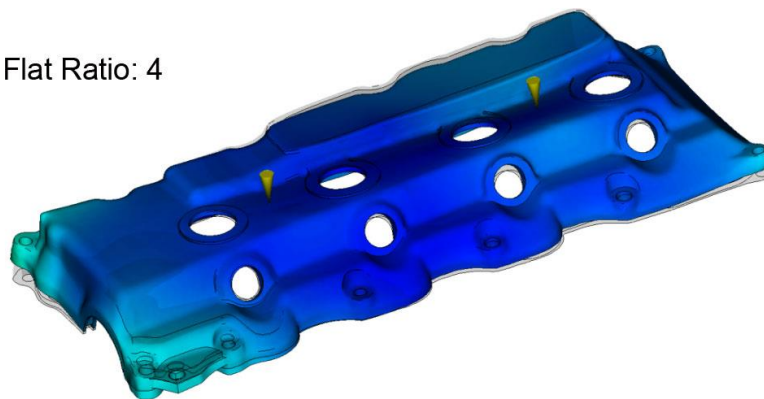


Figure 6: Comparative warpage analysis of the cylinder head cover produced with center double gate injection

Figure 7 summarizes the simulation results, showing that the magnitude of warpage decreases as the flat ratio of glass fibers increases. The figure also shows that the reduction in warpage can be achieved irrespective of the position of injection gate.

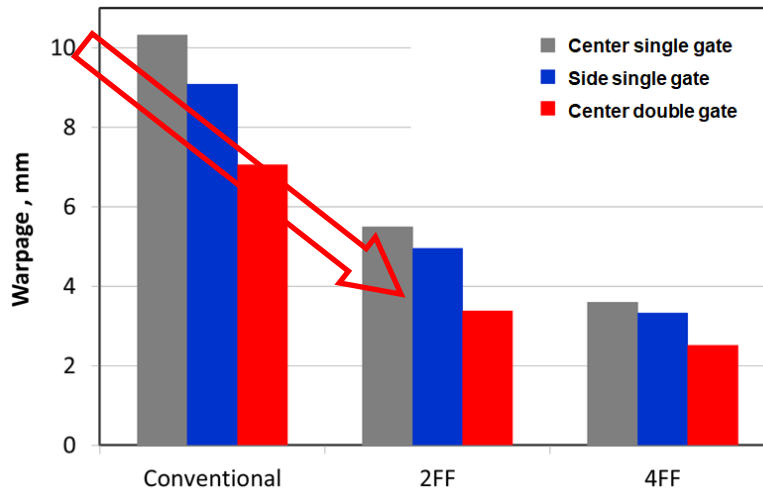


Figure 7: The magnitude of warpage decreases with increasing flat ratio

### Greater Tensile Strength

In addition to reducing warpage, the smaller anisotropy, resulting from the use of flat glass fiber, also enhances the physical properties of the composite material. Moldflow® software was also used to simulate and visualize the tensile modulus distribution in the molded cylinder head cover. Figure 9 shows that the flat fiber composite material, with a flat ratio of 4, exhibited the highest overall modulus. The modulus for the composite with flat glass fiber ratio of 2 was also higher than for the conventional glass fiber part. This result is important because it offers engineers greater flexibility in product design. It means that flat glass fiber composites can match the tensile modulus of conventional glass fiber components with a thinner layer or reduced glass fiber content. Thinner components can help engineers achieve further weight reduction leading to increased fuel efficiency of vehicles.

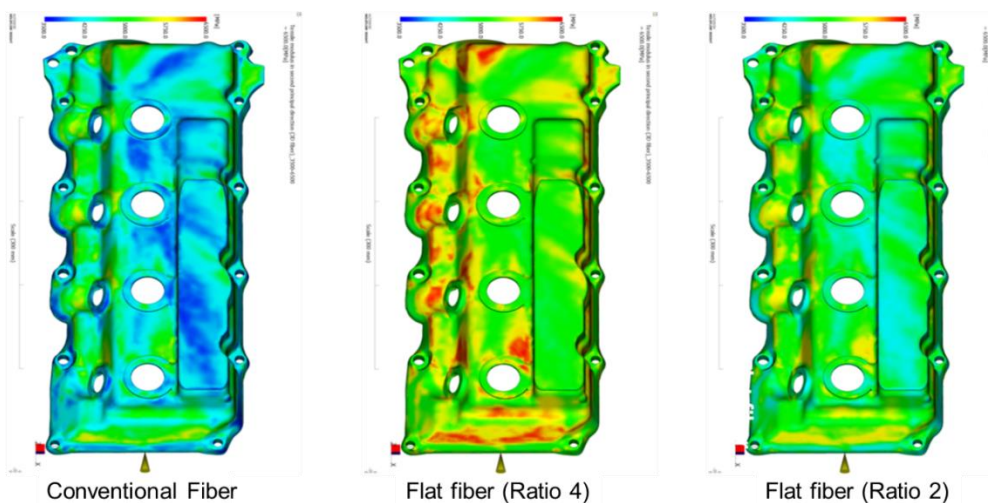


Figure 9: Simulation results of tensile modulus distribution in the molded part; flat fiber with a flat ratio of 4 shows the highest overall modulus

Test results show that the tensile strength of Nittobo flat fibers is greater than the tensile strength of conventional fibers with a circular cross section. Figure 10 shows that replacing round glass fibers with Nittobo flat fibers increases the tensile strength of FRP products. Nittobo fibers produce consistently greater tensile strength across a range of glass fiber weight percentages.

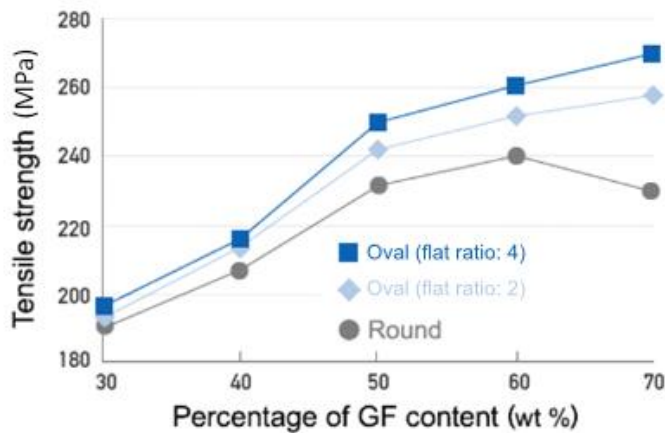


Figure 10: Nittobo flat fibers significantly increase the tensile strength of FRP products

### Less Deformation under Stress

Elastic gaskets are used to form a leak proof seal between the cover and the cylinder head. The compressed gasket that fills up any spaces between the two surfaces exerts a reaction force on the head cover. This reaction force can deform the cover breaking the leak proof seal. Simulations show that the enhanced physical properties of flat fiber reinforced composite reduce the deformation of the cylinder head cover. Figure 11 shows that the deformation in 4FF flat fiber reinforced composite part is reduced by approximately 20% as compared to the conventional fiber reinforced part. This means that the risk of oil leakage from the flange part can be reduced by substituting conventional fibers with flat fibers.

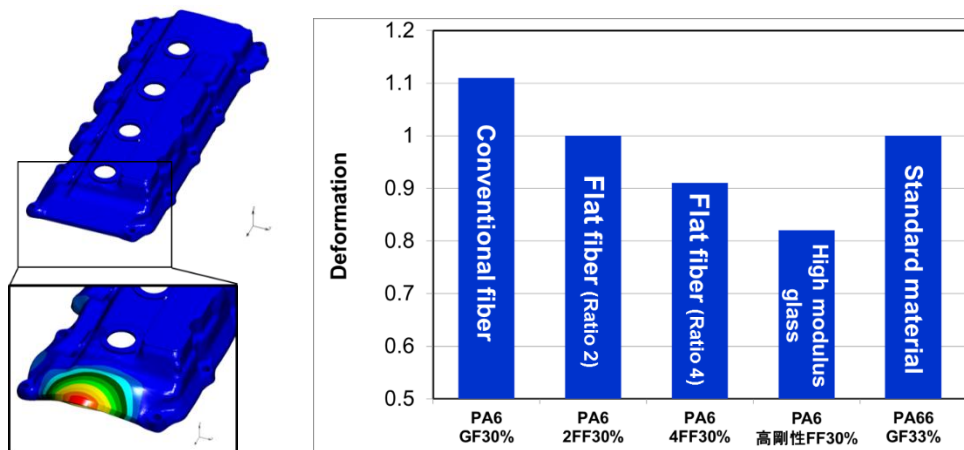


Figure 11: Deformation due to the elastic gasket is considerably reduced by flat fibers

## Cost Reduction

The superior physical properties of flat fiber reinforced composites increases the flexibility of design and material selection for engineers. Flat fibers can help reduce the manufacturing cost of an FRP part in one or more of several ways:

- The higher tensile modulus of the composite allows reduction in wall thickness of the part leading to reduced part weight and cost.
- The enhanced physical properties of flat fiber reinforced plastic may allow for downgrading of the polymer to a lower-cost alternative. For example, in some applications PA66 may be replaced by PA6 to reduce manufacturing costs.
- The enhanced strength of the flat fiber composite material may allow for reduction in the weight percentage of glass fiber required.

Table 2 compares and summarizes the composite material properties and dimensional characteristics of 4FF Nittobo flat fibers used in this study.

Properties	Method (ISO)	Units	PA6/GF30% Value	
Composite material properties			Flat fiber	Round
Tensile strength at break	572-1,2	MPa	170	170
Flexural strength	178	MPa	245	250
Flexural modulus	178	GPa	8.5	8.2
Flexural modulus (Transvers Direction)	-	GPa	5.5	3.8
Charpy Impact (notched; 23 °C)	179	kJ/m <sup>2</sup>	18	19
Dimensional properties				
Mold shrinkage (2mmt) (MD/TD)	-	%	0.3/0.6	0.3/0.9
Warpage (1mm <sup>t</sup> )		mm	4	12

*Table 2: Key properties of Nittobo glass fibers used in the study*

## Conclusion

Nittobo flat glass fibers can help reduce warpage in composite products. The magnitude of warpage decreases with increasing flat ratio of glass fibers, the flatter the fibers the lower the warpage. Nittobo flat fibers can help achieve low shrinkage and reduced anisotropy which makes them suitable for a wide range of applications that require good dimensional stability. These applications include critical engine parts and casings for small electronic devices that do not tolerate even the slightest distortion. Nittobo's flat glass fiber offers new opportunities to automobile manufacturers as they evolve their products towards electrification and high fuel efficiency. In addition to reducing warpage, Nittobo flat fibers offer the following advantages:

- Good dimensional stability

- Improved mechanical and physical properties
- Reduced deformation under stress
- Cost reduction due to improved performance
- Suitable for Polypropylene, ABS, PPS, Polyester and other super engineering plastics

**Nittobo can help you enhance your composite polymers**

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