

# Evaluation of Engineering Plastic for Rollover Protective Structure (ROPS) Mounting

R. S. Comer, P. D. Ayers, J. Liu

**ABSTRACT.** Agriculture has one of the highest fatality rates of any industry in America. Tractor rollovers are a significant contributor to the high death rate. Rollover protective structures (ROPS) have helped lower these high fatality rates on full-size tractors. However, a large number of older tractors still do not use ROPS due to the difficulty of designing and creating a mounting structure. To help reduce this difficulty, engineering plastics were evaluated for use in a ROPS mounting structure on older tractors. The use of engineering plastics around axle housings could provide a uniform mounting configuration as well as lower costs for aftermarket ROPS. Various plastics were examined through shear testing, scale model testing, and compressive strength testing. Once a material was chosen based upon strength and cost, full-scale testing of the plastic's strength on axle housings was conducted. Finally, a mounting structure was tested in static ROPS tests, and field upset tests were performed in accordance with SAE Standard J2194. Initial tests revealed that the ROPS mounting structure and axle housing combination had higher torsional strength with less twisting than the axle housing alone. An engineering plastic ROPS mounting structure was easily successful in withstanding the forces applied during the static longitudinal and lateral ROPS tests. Field upset testing revealed that the mounting structure could withstand the impact loads seen during actual upsets without a failure. During both static testing and field upset testing, no permanent twisting of the mounting structure was found. Engineering plastic could therefore be a viable option for a universal ROPS mounting structure for older tractors.

**Keywords.** Engineering plastics, Pre-ROPS tractor, Retrofit ROPS, Rollover protective structures, ROPS.

The agricultural industry has one of the highest fatality rates of any industry in the U.S. In 2003, the agricultural industry death rate was 20.9 workers for every 100,000 workers per year. This was over six times higher than the national industrial average rate and second only to mining (NSC, 2004). From 1992 to 2002, vehicles accounted for 52% of agricultural fatalities (NSC, 2004). Each year, the U.S. has averaged between 250 and 350 fatalities due to tractor-related accidents (NIOSH, 2004). Over 50% of these tractor-related deaths were due to an overturn (NSC, 2000).

Many steps have been taken to reduce the number of deaths caused by overturning tractors. A very successful step in lowering the number of rollover deaths was the addition of rollover protective structures (ROPS) to tractors (NIOSH, 2004). In Sweden, the government began requiring ROPS on all new tractors in 1959. By 1990, 93% of tractors

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in Sweden had a ROPS or safety cab structure (Springfeldt et al., 1998). The death rate at that time was less than one death per 100,000 workers, 24 times lower than in the U.S. (Thelin, 1998).

In 1993, there were around 4.8 million tractors in use on U.S. farms. Roughly 1.8 million of these tractors had ROPS in place (Myers and Snyder, 1995). This left more than 62% of tractors without rollover protection. It was estimated that at the current pace of replacement and retirement, if no further retrofitting occurred, it would take 24 years for 74% of tractors in use to have ROPS (Myers and Snyder, 1995). According to Myers' (2003) latest projections, there were 4.8 million tractors in use in 2003, and 2.46 million (51%) of them were without ROPS.

Many older tractor models do not have protective structures available for them. This is partially because the cost and complexity of manufacturing a mount have made it unfeasible to produce aftermarket ROPS (Li, 1997) for all models. The mount consists of the structure that attaches the ROPS to the axle housing. The difficulty in designing ROPS mounting structures arises from the various shapes of the axle housings. Since many tractor models do not have square or hexagonal axle housings, they cannot use a standard compression-fitted mounting structure. An example of this is the Allis Chalmers D-17 (Ayers, 2003). This model is the fifth most popular pre-ROPS tractor (Myers and Snyder, 1995). A pre-ROPS tractor is a tractor that was manufactured without a ROPS mounting structure designed into the axle housing or chassis. In 1993, there was over 41,000 D-17s still in use. This was also the most used tractor model without some type of retrofit ROPS available (Myers and Snyder, 1995).

## Objective

The objective of this study was to evaluate the feasibility of using an engineering plastic as part of a ROPS mounting structure on tractor axle housings. The concept of this project was to develop a metal box that encloses the axle housing at the ROPS mounting location. This mounting box was then injected with engineering plastic to adhere to the axle housing and provide support to keep the box from rotating. The specific engineering plastic used for this study was chosen based on previous research pertaining to engineering plastic strengths (Comer, 2005). The ROPS would then be attached to this mounting box with a compression-fitted mount. The specific objectives of this project included three main evaluations:

- Evaluation of the torsional strength of an engineering plastic-filled ROPS mounting structure fitted on an Allis Chalmers D-17 axle housing.
- Evaluation of the engineering plastic mounting structure during a static ROPS tests.
- Evaluation of the engineering plastic mounting structure during field upset tests.

To fulfill the objectives of this project, the research was broken down into three phases that corresponded to the objectives. The first phase of testing was to conduct torsional tests of the axle housing and plastic-filled mounting box combination. This was done to see if the combined system would have the torsional strength of the axle housing alone. The loads for this test needed to be greater than 38,000 N·m, the yield torque of the D-17 axle housing as determined by Ayers (2003). The second phase was to install the axle housing and mounting box combination, with a ROPS, on a D-17 tractor chassis. The ROPS was then be subjected to a static longitudinal and lateral tests as specified in the SAE J2194 standard. The third phase of testing was done to validate the static tests. In this phase, a fully functional D-17 tractor was implemented with plastic-filled mounting boxes and a ROPS. This tractor was then subjected to field upset test as specified in SAE J2194.

# Methods and Materials

## Phase One: Axle Torsion Load Test

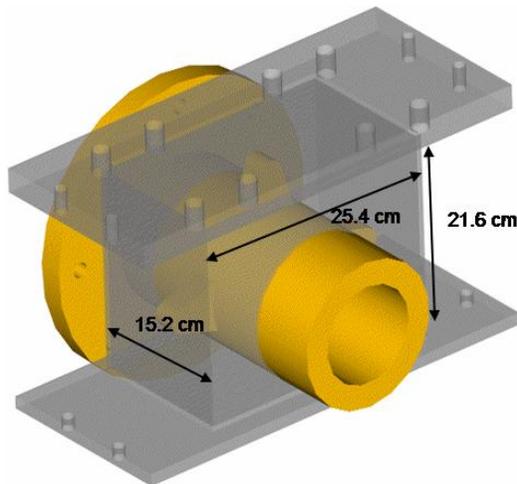
Phase one testing of the axle housing and mounting box combination was completed at the Agricultural Engineering Research Center at Colorado State University in Fort Collins, Colorado. The parts used for this test were an Allis Chalmers D-17 axle housing and the ROPS mounting structure injected with engineering plastic. Mounting boxes were fitted around the axle housing where the fender mounting lobes were located, with the lobes inside the box. Once the boxes were in place and sealed, engineering plastic was poured into them through holes on top of each box. During testing, the axle housing and box combinations were subjected to torsional loads until a failure occurred or the load surpassed the D-17 axle housing maximum yield torque (38,000 N·m).

### *Mounting Box Preparations*

To fit a box around the fender mounting lobes, boxes were constructed to be 25.4 cm by 15.2 cm base with a height of 21.6 cm. The outside radius of the axle housing was approximately 8 cm at the box location. The wall thickness was chosen to be 0.95 cm (3/8 in.) to reduce possible bending of the box sides during testing. Each box was made in two sections, a top and bottom, which fit around the axle housing and were then welded together. Figure 1 shows an example of a mounting box on an axle housing.

Since the torsional load test used an I-beam that was bolted to the top of each box, a thick top plate was needed to provide an ample number of threads to hold the I-beam in place. A compression fit around the mounting box would have required exceedingly long bolts. Eight bolt holes were drilled in the top plate and tapped, along with two 2.54 cm holes (not shown). These two 2.54 cm holes were plastic pouring inlets. The bottom plate was made of 1.27 cm thick cold-rolled steel. The four small holes on the ends of the bottom plate were used to hold the box halves together as the engineering plastic cured.

Before mounting the box on the axle housing, the axle housing section that would lie inside the box was cleaned with a solvent and wire brush. Expandable foam was injected around the axle housing's diameter to seal the areas where box and axle housing touched. Once this foam had cured, engineering plastic was poured into the boxes.



**Figure 1.** CAD isometric view of a mounting box on an Allis Chambers D-17 axle housing.

The steel boxes completely surrounded the plastic and were left in place during testing. This reduced the risk of UV weathering, since the engineering plastic was encased within the box. However, this study did not evaluate any weathering or temperature effects on the engineering plastic's performance.

### *Engineering Plastic Preparations and Pouring*

The engineering plastic used in this study was chosen based on previous research. Engineering plastics with a low viscosity, ambient curing temperature and pressure, and high tensile strength were examined (Comer, 2005). Of the various materials examined, Liquid Iron (RenCast 3215-3, Freeman Manufacturing and Supply, Co., Avon, Ohio) performed the best in shear strength (28.62 MPa), torsional resistance (6227.72 N·m), and compressive strength (82.1 MPa) testing (Comer, 2005). Freeman's Liquid Iron is an iron oxide-filled, variable-hardness, two-part epoxy. The engineering plastic poured into each box was estimated to have a total volume of approximately 5,500 cm<sup>3</sup>.

Freeman's Liquid Iron has a volume to weight ratio of 0.65 cm<sup>3</sup> per gram, meaning that each mounting box would hold approximately 9 kg of engineering plastic. Following the mixing procedure given by the manufacturer (10 parts resin to 2.5 parts hardener by weight), the two components were weighed and combined to make 9 kg of engineering plastic. The plastic was then slowly poured into the 2.54 cm open holes on top of the box and left to cure for the recommended time of at least seven days. Once the engineering plastic was cured, the combined box and axle housings were ready for testing.

### *Testing Setup*

To conduct torsional load testing, an axle housing's differential end was bolted onto a bracket of the testing apparatus base frame. This was done to prevent movement of the housing relative to the testing apparatus. The wheel end was held up with a pin mount (to allow rotation, but not translation) on a second bracket to reduce bending loads. With an axle housing mounted securely to the test frame, an I-beam was bolted to the mounting box's top plate.

A hydraulic cylinder was attached to the I-beam at 1.98 m above the centerline of the axle housing. The hydraulic cylinder had a piston diameter of 10 cm and a stroke of 60 cm. Cylinder displacement was at a rate of approximately 0.35 cm/s. A 90,000 N load cell was mounted in line with the hydraulic cylinder to measure loads applied to the I-beam. As the cylinder extended, a potentiometer was used to measure the length of extension. Both the load cell and potentiometer measurements were logged into a Campbell Scientific 23X data logger. The logging rate was once every 0.2 s. Measurement accuracies for this system were  $\pm 41$  N and  $\pm 0.1$  cm.

During cylinder extension, twisting of the axle housing was observed through videotape review and cast line distortion. The cylinder was extended until the load surpassed the loading placed on previous D-17 axle housings. The cylinder was then returned to a no-load situation. Previous torsional testing research was conducted on D-17 axle housings by Ayers (2003). Their data were available for comparison with the data collected during this phase of testing. The testing was conducted on two identical mounting boxes on two different axle housings. Observations were made after each test about the failure or amount of twist.

## **Phase Two: Static ROPS Testing**

The second phase of testing was also completed at Colorado State University's Agricultural Engineering Research Center. In this phase of testing, axle housing and mounting box combinations were tested to determine if they could withstand loads applied during longitudinal and lateral static testing per SAE J2194 (*ASAE Standards*, 2004). To conduct this test, a set of axle housings with mounting boxes was attached to a differential housing

from a D-17 tractor. A ROPS was then attached to the mounting boxes so that the loading called for by the standard could be applied.

### *Mounting Box Setup*

The mounting box dimensions for this testing were the same as used in phase one, but the top and bottom plates were reduced in thickness. This was due to the fact that the ROPS was not bolted to the top plate but instead was attached to the mounting box with a compression fit. Therefore, since no threads were required, the plates did not have to be as thick. In addition, the box halves were not welded together during this phase. When the two halves were placed around the axle housing, they were compressed together using four bolts. Expandable foam was used to seal between the box halves and around the axle housing. With the halves compressed and sealed, engineering plastic was mixed and poured into the box, as in phase one. The bolts securing the box halves were then used to mount the ROPS with a compression fit.

### *Testing Setup*

Mounting box and axle housing combinations were bolted to the test frame. The ROPS was then mounted using a compression fit around each mounting box. The first test conducted was a longitudinal static test. The tractor mass of a D-17 is 2,118 kg, as given by Nebraska Tractor Test No. 635 (Nebraska Tractor Test, 1957). This mass required a test energy of 3,200 J when 10% was added to the equation's given amount to account for test stand deflection.

The same test apparatus that was used in phase one was used for this test. The load was applied horizontally with the hydraulic cylinder placed on the rear of the ROPS cross-beam "one-sixth of the width of the top of the ROPS inward from the outside corner" (ASAE Standards, 2004). A potentiometer and load cell again recorded force and displacement. These values were logged into a Campbell Scientific 23X data logger. The data logger program calculated the energy applied at each sampling interval along with the total energy applied. Once the total energy absorbed by the ROPS passed 3,200 J, the loading stopped and the hydraulic cylinder was retracted.

After conducting the longitudinal test, a lateral static test was performed. This test is similar to the longitudinal test except that the load is applied to the uppermost part of the ROPS side. The energy absorption required for a D-17 was 4,100 J when 10% was added.

To successfully pass these static tests, two events must happen. First, the ROPS and its mounting structure must withstand the loading needed to achieve the energy requirements. Second, the deflection of the ROPS during testing must not enter the operator protective zone, as described in SAE J2194, or expose the operator protective zone to the ground (ASAE Standards, 2004). Maximum longitudinal and lateral deflections were found by using a model to evaluate exposure. This model, from Ayers et al. (1994), uses various measurements of the tractor and ROPS to calculate maximum allowable deflections. Maximum longitudinal and lateral deflections were 41.5 and 40.0 cm, respectively.

### **Phase Three: Field Upset Testing**

Longitudinal field upset testing was done to validate the results from the phase two testing. The field upset test is a controlled method for executing a tractor rollover based on SAE J2194 requirements. To fulfill the objectives of this test, a tractor was driven at a constant velocity, under its own power, onto and up a 60° inclined ramp (ASAE Standards, 2004). As the tractor traveled up the ramp, a rearward roll was produced. ROPS deflection was measured to ensure that the operator protective zone was not intruded upon or exposed to the ground. This was done through use of a slide bar attached to the top ROPS post, since it measured both elastic and plastic deformations.

A ROPS was attached to the tractor in a similar fashion as in phase two. Box halves were bolted around the axle housing at their mounting locations, and foam was used to seal the seams. Once the boxes were in place, engineering plastic was mixed and poured into them. After the recommended curing time, a ROPS was compression fitted onto the mounting boxes. The material and dimensions of the ROPS were identical to those used in the static testing. This meant that the allowable ROPS deflection would be equal to 41.5 cm for a longitudinal roll.

The D-17 tractor was equipped with a radio control system so that it could be driven remotely from a safe distance. The clutch and brake pedals were controlled through pneumatic cylinders, and steering was controlled through a reversible DC motor. In addition, a safety cutoff switch was included to kill the motor if needed.

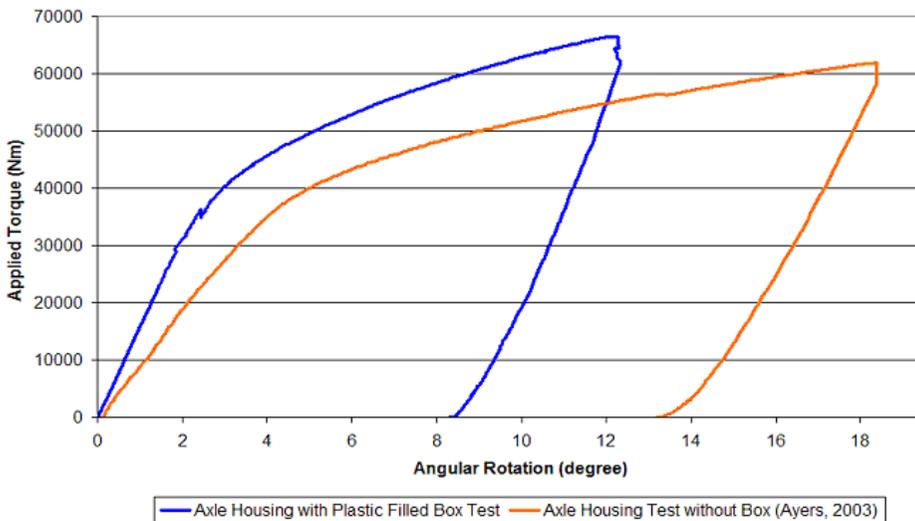
## Results

### Phase One: Axle Torsion Load Test

After data were collected, a maximum torque of around 66,500 N·m was found for each test conducted. Each test of the engineering plastic mounts was nearly identical when comparing the torque versus axle housing twist curves. These curves also clearly illustrated the point at which the axle housings entered the plastic deformation range. An example of the torque versus angular rotation is given in figure 2.

Also shown in figure 1 are the results of previous tests that were conducted on D-17 axle housings without mounting boxes. Ayers (2003) mounted the I-beam directly to the top of the axle housing. When compared to the previous testing of axle housing strength, the plastic-filled mounting boxes provided an increase in torsional strength with less angular rotation. The maximum torque applied increased from 61,990 to 66,494 N·m when the plastic-filled mounting boxes were used, and angular rotation decreased from 18.3° to 12.3°.

Deformation of the engineering plastic was easily noted, since the axle housings did not return to their original state. It was also observed that the twisting took place in line



**Figure 2. Comparison of axle housing torsional resistance for a D-17 axle housing with and without a mounting box.**

with the fender mounting lobes. When looking down the inside of an axle housing, a casting line, where the twisting originated, was easily identified. Since this twisting originated at the fender mounting lobes, it was thought that the lobes carried the bulk of the load applied to the housings, as expected. No visible permanent change in the box position was observed. If there was such a change, it was minimal when compared to the twisting of the housing. This indicates that the boxes stayed firmly in place and that all twisting was due to deformation of the axle housing.

### Phase Two: Static ROPS Testing

Results from the longitudinal and lateral tests are shown in figures 3 and 4. These figures show both the force applied and the energy absorbed. Energy absorption requirements were met during both tests. Longitudinal testing demonstrated that the energy requirements were met at a deflection of 22.3 cm and a force of 25,000 N. This deflection was slightly more than half the maximum allowable deflection of 41.5 cm, which was established to meet the intrusion and exposure criteria. Data from the lateral testing demonstrated that the energy requirements were met at a deflection of 16.3 cm and a force of 44,000 N. This too was well below the maximum allowable deflection of 40.0 cm that was calculated by Ayers' (1994) model. Although these results are dependent on the ROPS design, the mounting box appeared to support the stress applied during the static tests.

Observations after testing confirmed that the mounting boxes did not show any permanent rotation on the axle housing. In addition, there was no permanent twisting of the axle housing. This could be attributed to having the loads carried by two axle housings during the tests. There were no signs of box failure during either of the static tests.

### Phase Three: Field Upset Testing

With a fully functional tractor in front of the ramp, a gear was selected to reach the desired speed. When the clutch and brake were released, the tractor moved towards and up the ramp until it rolled backwards. Slide bar measurements were taken after the successful roll. Elastic deformation was found to be 6.0 cm. A plastic deflection of 2.2 cm

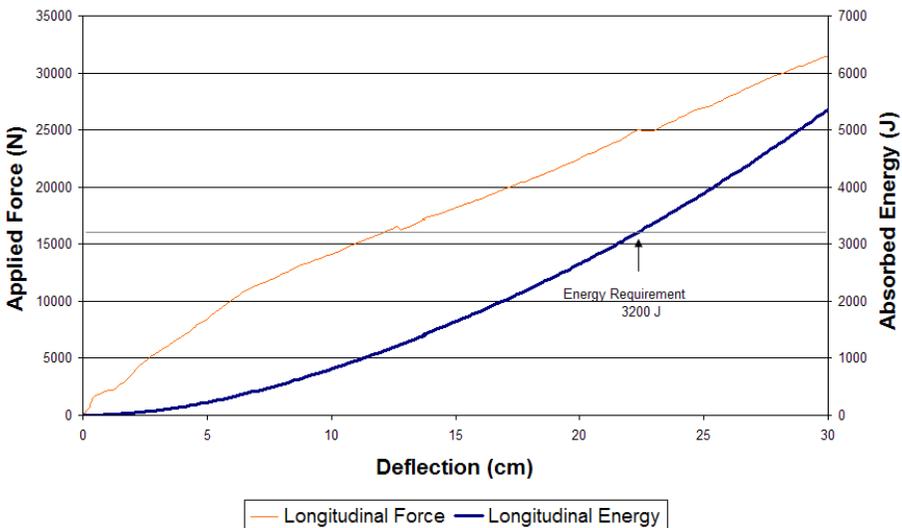
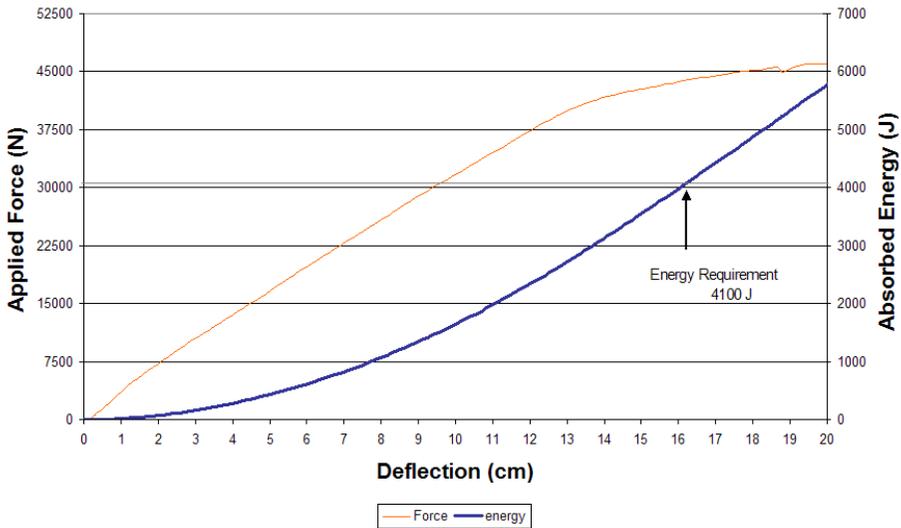


Figure 3. Static longitudinal test results.



**Figure 4. Static lateral test results.**

was also measured. This gave a total deflection of 8.2 cm, well below the allowable 41.5 cm. This was also much lower than the deflection seen in the static testing (22.3 cm). No permanent rotation of the mounting boxes was observed during the field upset testing. This indicated that the engineering plastic-filled boxes had sufficient torsional strength to withstand the impact forces produced during longitudinal rolls.

## Conclusion

The objectives of this study were to evaluate engineering plastics for ROPS mounting by:

- Conducting torsional testing of the axle housing to evaluate the strength of the engineering plastic mounting box.
- Conducting static longitudinal and lateral testing of the engineering plastic mounting box on an axle assembly with a ROPS installed.
- Conducting field upset testing of a tractor with a ROPS installed using engineering plastic mounting boxes.

Each of these objectives was completed and evaluated through testing. The tests fulfilled all objectives, confirming that the engineering plastic mounting box is sufficiently strong and provides a useful solution to the problem of ROPS retrofitting.

Testing of the engineering plastic's strength on an axle housing was conducted by combining an Allis Chalmers D-17 axle housing with an engineering plastic-filled mounting box. Torsional tests revealed that the axle housing and mounting box combination had higher torsional strength with less twisting than the axle housing alone. Peak torque applied was 66,494 N·m at an angular rotation of 12.3°. Previous testing of a D-17 without an engineering plastic-filled mounting box showed a peak torque of 61,990 N·m at an angular rotation of 18.3° (Ayers, 2003).

A ROPS was installed with engineering plastic-filled mounting boxes and subjected to longitudinal and lateral static tests in accordance with SAE standard J2194. These tests showed that the ROPS withstood the energy requirements at deflections of 22.3 cm

longitudinally and 16.3 cm laterally. These values are well below the calculated maximum allowable deflections (41.5 cm longitudinal and 40.0 cm lateral) established to keep the ROPS from exposing or intruding into the operator protective zone.

The final test was a longitudinal field upset test. A working D-17 tractor with a ROPS and an engineering plastic mounting structure was tested in accordance with SAE J2194 field upset test requirements. Results from this test showed that the tractor passed the standards requirements; ROPS deflection was 8.2 cm, again well below the maximum allowable longitudinal deflection of 41.5 cm.

While the engineering plastic used in this study has proven to be useful as a mounting material for ROPS, further research is needed. Research should be conducted on the life expectancy and material compatibility of the engineering plastic. In particular, how does this material handle vibrations caused by use on a tractor? In addition, how does the material react to corrosive chemicals, extreme temperature, and cycling temperature changes?

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