Challenges to Develop a Polymeric Diesel Filter

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ABSTRACT

Metal diesel filters for heavy and medium duty were applied in automotive market in the last decades. However, new energetic efficiency trends and final user demands force new developments to reduce product weight, improve serviceability and decrease trash disposal.

Polymer application brings advantages because it uses materials with lower density and allows implementation of complex product designs with fewer components. However, its application requires an intensive effort, as temperature and chemical attack affects the polymer properties in more intensive way than metal. In this way, aiming the optimum balance between performance and cost, a concept of polymeric diesel filter has been created.

First strategical point was material characterization. Several aging tests were implemented considering environment conditions to understand the material properties impact. Second strategical point is related to fast and robust numerical simulation. New methodology was implemented to develop a less complex and fast numerical simulation. This initiative allows the designer to be more audacious in the product concepts and get a fast feed-back about directions to be followed.

This paper presents the methodology to develop a polymeric diesel filter and results in comparison to metal filter.

INTRODUCTION

Polymeric diesel filters is a product concept aligned to the future market trends. Its reduced weight is related to material lower density in comparison to structural materials like aluminum die-casting (1,4g/cm³ against 2,8g/cm³). Polymers also allow higher design flexibility with fewer components. Using injection molding devices like sliders and post-injection process like welding, polymer part design can be complex without impacting in high piece cost. This lower density applied to more complex designs allows new product concepts linked to weight reduction, improved serviceability and less trash disposal.

Weight reduction has a significant impact on vehicle emissions and performance [1]. In conventional internal combustion engine light-duty applications, a 10% vehicle weight reduction can result in a 6%-8% improvement in fuel economy. For load-limited, weight reduction can also result in increased freight capacity and improvement in delivered ton-miles per gallon. Vehicle light weighting can reduce the number of trucks required to ship a given tonnage.

Total cost of ownership (TCO) is an important indicator by estimating direct and indirect cost of owning and using a vehicle [2]. This is even a more critical item at heavy and medium duty segment. Reason is related to high mileage and consequent higher number of maintenance services applied in truck, buses and agricultural applications. In this way, expenses related to filtration replacement (oil, air and fuel filters) like filters piece price, service interval and necessary time to replace a filter have a high impact in the total cost of ownership. Filter concepts that have their service part cheaper or higher dust holding capacity (and related higher service interval) or easier maintenance (and shorter replacement time) are strategical requirement for new technologies introduction.

Fuel filter trash disposal reduction is also important due to environment contamination potential and need of correct recycling process. Regulations like Assembly Bill 2254 [3] effective since 2005 by State of California requires that fuel filter disposal management needs to be similar to oil filter and managed separately according to specific rules.

However, polymer material properties are not the same as metal parts. In general, polymers are more sensitive to temperature and chemical attack. Different material fillers and additives were developed by the resin suppliers in order to mitigate this impact. But, unfortunately, it increases resin cost and/or product manufacturability in different ways. In this way, a large number of material and design combinations are possible and result in innumerous design concept alternatives. Therefore, a methodology to develop polymeric diesel filter is necessary in order to bring a balance development effort and product benefit.

1. DEVELOPMENT METHODOLOGY

In order to find the optimized solution within planned budget and lead time, high effort is necessary at numerical simulation. Virtually analyzing the product concept is possible to reduce expenses and lead time in prototyping and several design loops. Beside this, design concept can be out-of-common solution as the designer can be creative and take more risks.

However, numerical simulation results, many times, do not fit exactly the final parts performance. More common reasons are that material properties are not according to real life conditions and thus the performance could not be correct defined. Specifically related to polymeric parts, polymers with material fillers like glass fibers have a non-isotropic behavior. It means that, depending on glass fibers distribution inside the parts, part mechanical properties are not uniform and differ depending on force direction.

Reducing the numerical simulation confidence level, over engineered parts can be designed or failures in the prototyping phase can happen. In this way, full material performance will not be properly used and final product will not achieve project expectations.

Presented development methodology objective is to increase this confidence level and allow more complex design implementation. Basically, there are two main pillars in this strategy: optimized material characterization and different levels of numerical simulation.

2. MATERIAL CHARACTERIZATION

Resin suppliers provide to development teams material properties data sheet tested according to international standards. This information is quite important as you can compare different materials performance according to market known standards and decide which best fit your project demand according to costs and performance. However, sometimes this information is not the ideal for numerical simulation purposes.

Considering diesel filters, application and laboratory test conditions differs from material properties data sheet. At application condition, filter is exposed to high temperatures and diesel/biodiesel chemical attack during vehicle life time and fatigue conditions. At laboratory, parts are exposed to intensive thermal shocks and high loads during pulsation cycles. In this way, adequate and specific material properties characterization was necessary to correct define numerical simulation parameters.

In order to do this, tests with high temperature and diesel/biodiesel blends were implemented in partnership with resin suppliers.

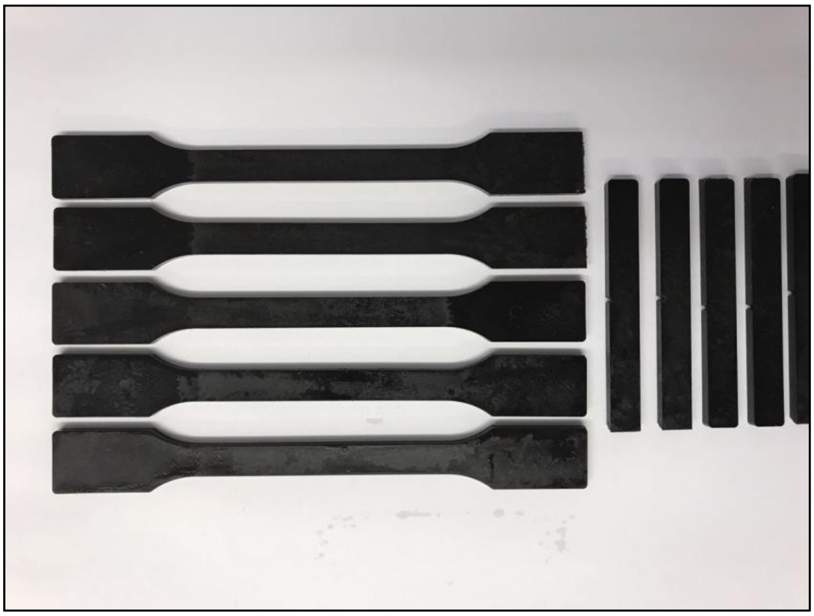

Figure 1: Polyamide bar samples after diesel/biodiesel hot soak

Beside this material experimental procedure to determine material mechanical properties, additional studies were necessary. For instance, when using welding process, material degradation happens due to process high temperatures and a safety factor is necessary to be applied. Fatigue conditions are also an important issue not possible to be simulated at hot soaking experimental test. In this way, specific studies are necessary in order to determine lifetime conditions under pressure and predict material performance reduction.

3. NUMERICAL SIMULATION IN DIFFERENT LEVELS

Traditional numerical simulation procedure considers polymer material properties as isotropic conditions. It means that mechanical properties are the same in different directions. When working with polyamide with glass fiber content, material properties are higher but not the same in all directions due to fiber orientation. In this way, anisotropic numerical simulation is necessary in order to increase results to real life.

However, this procedure increases numerical simulation lead-time as more complex calculation is necessary in order to predict this non-homogeneous condition. In this way, a numerical simulation in different levels was considered.

At the beginning, a first design concept is implemented by design engineer and submitted to non-isotropic numerical simulation. This first concept has the focus in the material thickness reduction, and consequent weight lightening, and high complex geometry in order to reduce quantity of components. Normally this procedure takes one week and shows component more critical areas to mechanical load and fatigue.

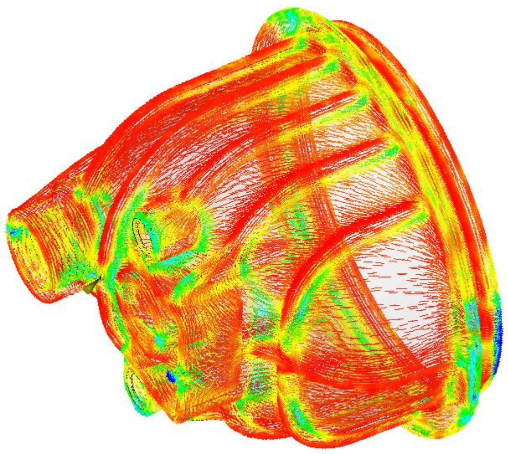

Figure 2: Glass fiber distribution inside part

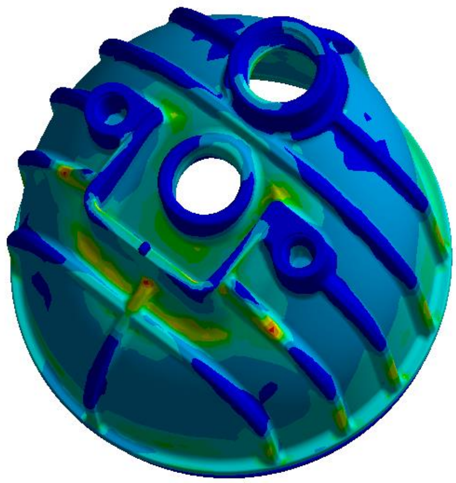

Figure 3: Anisotropic simulation

As second step, a quite more simple numerical simulation is implemented under isotropic conditions and low mesh resolution in comparison to traditional numerical simulation procedures. As consequence, simulation results are not accurate as first round analysis, but a baseline condition is determined.

Taking in consideration this baseline design, new product concepts are implemented in sequence and simple numerical simulation looping are done in order to give a short term feed-back to designers about their actions. Doing this, about 18 different designs were simulated in the same day in order to check quality wise improvements in the product concept.

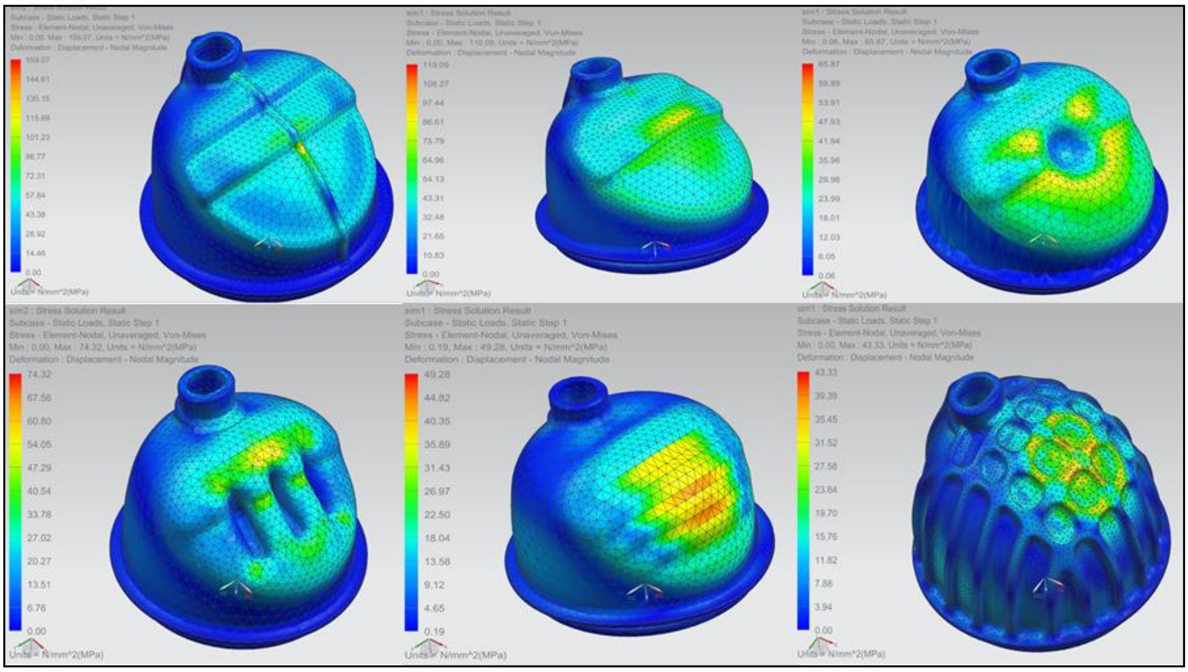

Figure 4: Six of the eighteen designs checked using fast response simulation

Doing this design quality evolution check through simulation, designer team has more flexibility to create out-of-common design concepts achieving maximum material performance as not always the ideal solution is the most obvious concept.

As third level, the optimized design is submitted to the more complex solution with anisotropic conditions and detailed mesh in order to confirm the final strengths values according to material properties evaluated in the material characterization conditions.

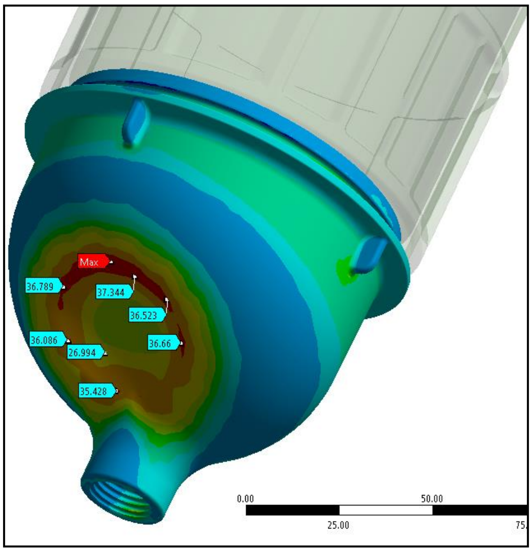

Figure 5: Final design approved in the third level numerical simulation

CONCLUSION

Development methodology using material characterization and numerical simulation in different levels allows robust design development with innovative solutions within reduced timing and budget. Using it for a polymeric diesel filter development, it was possible to predict part performance in application and laboratory tests without several loops during prototype phase.

As result, weight reduction was obtained using polymers instead of die-casting filter head. In comparison to a similar concept filter, weight was reduced from 2,4kg to 1,8kg (25% reduction). Total cost of ownership was also reduced through easier serviceability. Instead of traditional thread connection between filter head and filter housing, a bayonet coupling system was implemented. This action eliminates the need of two special tools necessary for service and allowed maintenance procedure only by hands in shorter time (50% less time). Trash disposal was also reduced in comparison to stamped metal filter. Service element was reduced from 0,8kg to 0,3kg without the need of metal separation during recycling procedure.

REFERENCES

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DEFINITIONS/ABREVIATIONS

TCO	Total cost of ownership