

TECHNICAL BULLETIN: DESIGN OF PLASTICS PARTS



This article is a free adaptation of the article entitled Distinguishing Features of the Mechanical Design of Plastic parts. Commentaries for the Undergraduate Student. S.I. Krishnamachari, Pioneer Technologies, Inc. Naperville, IL.

The creation of new technologies and materials in the plastic industry has allowed the ongoing replacement of other materials such as metal, paper and ceramic in several industrial applications. Less weight, less costs and better appearance are some of the reasons that have allowed the growth on the uses of plastic products worldwide. Unfortunately, the design criteria of plastic materials have followed the guidelines for the design of more rigid materials.

The process to achieve an efficient design of parts under such conditions involves two basic stages: the design of the part and individual elements (such as reinforcement nerves, holes, edges, etc.) and the analysis of efforts depending on the final application of the part.

Herein below are featured the most important design parameters that must be taken into consideration in order to manufacture plastic parts. The purpose is that readers can learn about the design criteria of different materials depending on the final application, as well as the minimal conditions required that will ensure both manufacturers and consumers a good-quality part.

1 Analysis of Efforts for the Mechanic Design of Plastic parts

The analysis of efforts which a part will be submitted is essential when designing a product with certain mechanical requirements. This analysis is based on the basic properties of plastic materials, as well as on different load stages (stockpiling, stretching, flexion, etc), in which an application could be developed. Even, it is also modeled those cases of improper use of the application in order to prevent failures, or suggest modes of use.

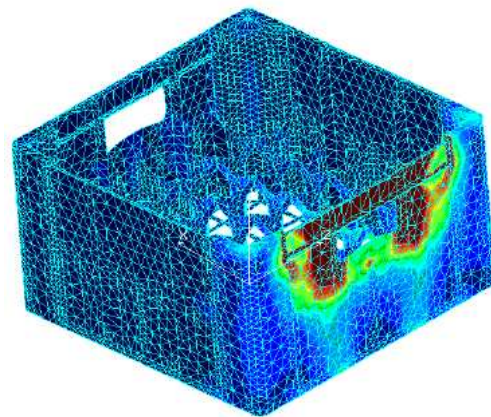
The design factor that involves such features is called **Safety Factor (SF)**, which in order words is an *unknown factor*. The SF warrants that the design

complies with all the mechanic requirements of the application, even if there is a large difference between the real life and the obtained theory of the idealized models of analysis, as well as the availability of a great amount of unquantified elements that could affect the design.

The chosen SF must reflect aspects such as the behavior of the material, economy of use, service conditions and others. Therefore, the SF could be dimensioned in a different form for different products, materials and specific modes of material failure. The Table 1 (at the end of this bulletin) features some SF recommendations for different conditions of use. Now, we are going to explain the different criteria of use:

2 Static Resistance and Rigidity

The Static Resistance and Rigidity are the most specific requirements for plastic parts. However, when both conditions are required in unloaded materials, the rigidity requirements must be predominant. These parameters depend on the resistance to a short-term fluency, and well as the tensile module. In most of the technical data sheets of the products, these values are specified.



Normally, it is considered that a SF of 1.5 in the effort of fluency and desired deflexion results in a proper protection in order to achieve a static resistance and rigidity. This SF value is a

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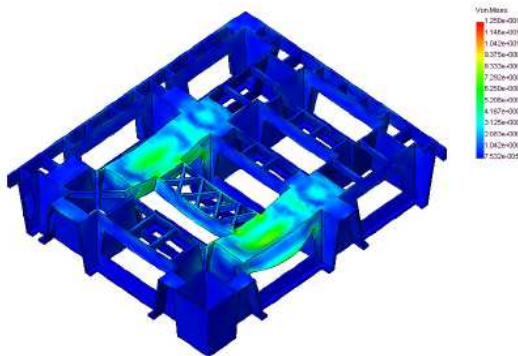


traditional value, and it has been applied successfully in metal and nowadays in plastics.

Historically, this SF was set when there was not a detailed knowledge on the resistance of materials, and when there was not developed the theory of the concentration of efforts. Therefore, an SF of 1.5 was used in order to avoid the concentration and fluency. In most of the cases, depending on the application, this value tends to be very high and results in an excess of material, high-cycle times and generally a higher unit cost per part.

In the case of deflexion, it is also necessary the application of this SF value as it must be considered the accumulative effects in a long-term basis. The deformation can be unacceptable in the long term; even it could fail with low effort levels.

On the other hand, it must be considered that most of unloaded plastics tend to suffer a high creep¹ during the early stages of static load, thus the application of this SF is extremely important.



Let's take the case of a 210-liter container that must be stockpiled in 3 or 4 levels. If this part is not properly designed, the container at the bottom may suffer the effect of "elephant leg" due to creeping.

Even if this effect does not cause a catastrophic rupture of the part, or the spilling of the contents, the situation is unacceptable as the container

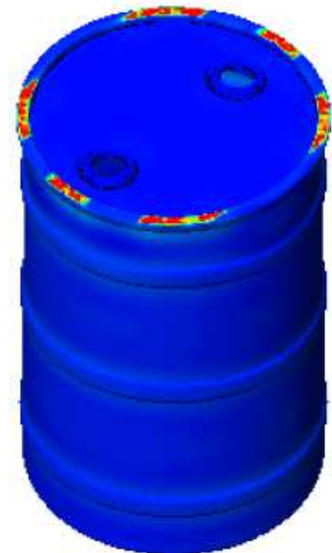
¹ Creep is a slow fluency or deformation of materials when are under loads during extended periods of time. Thermoplastic materials are much more sensible to creeping than metal, glass or even wood.

cannot be stockpiled due to its new shape. Therefore, the short-term deflections must be restricted in a better way.

Polinter offers to its customers these types of services as part of the technical assistance and the development of products.

3 Non-Linear Effort-Deformation Behavior

The relationship between the effort (and applied load), and the deformation (or deflexion) of a part under loads, when the deformation and / or efforts are low, it tends to be proportional, elastic and recoverable, and related through the elastic module that can be measured in different ways. In most of the cases, it is desired that the load status of any part are placed in these zones, as the deformation



ceases once the load is stopped. However, it is necessary in certain occasions to perform the analysis to loads or deflexions that exceed such status. A simple elastic-linear analysis can be used in order to calculate the effort or deflection of any part that shows a non-linear elastic behavior. It is necessary to adjust the SF only by using the relationship between the tangent module and the secant module. This SF is given then by: $FS=1.5[E_{tan}/E_{sec}]^2$.

This SF value is chosen as materials with non-linear behavior have magnified deflexions until $[E_{tan}/E_{sec}]$

² For further information about the different methods of measurement of modules, please contact your seller or the Marketing Management of Polinter.

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as maximum. Therefore, the problems of rigidity are solved with this factor.

The resistance of the material is given by a permissible deformation. In the areas of concentration of efforts, it is reasonable to assume that the effort can be read upon the movement-load curves, without applying to advanced methods such as computer simulation. However, the SF value hereinabove mentioned is too conservative, so it might be required proper simulations as an alternative to analyze the deflection, wherein the SF scale is not necessary at all.

4 Fatigue

It is understood the submittal of a part under a cyclic effort. Maybe the most representative effort is the "flip" lid of a toothpaste tube.

The structures that suffer a fatigue load require a very high SF value given the amount of cycles of fatigue. It is recommended a $SF = 10$ on the amount of cycles, or a $SF = 2.0$ in effort. For example, let's take a case of a part that required over 50.000 cycles of load. Based on the fatigue curve of the material, it is obtained an effort of 25 Mpa for 50.000 cycles. Therefore, the recommendation can be any of the following:

- Find the effort corresponding to 500.000 cycles (by using a $SF = 10$ in the amount of cycles) and limit the effort in the concentration areas to this value. This determination might be complex if there is a lack of the proper laboratory equipments.
- Limit the effort in the areas of concentration to 12.5 Mpa (it means, use a $SF = 2$ in the effort). In this case, traditional methods of analysis of effort or static load simulations should be used.

The reasons why this SF is so high is due that the beginning of the failure due to fatigue is very sensitive to microscopical local imperfections in the place of failure, that depend on several variables that are difficult to control, Either by the manufacturer of the resin, as well as by the transformer. It is also very common that the imperfections and high efforts happen

simultaneously in the same place, and such vulnerabilities cannot be quantitatively considered in the design, therefore a SF must be pursued. It is important to mention that it must be considered for all the modes of failures locally sensible, and not only for fatigue cases.

Given the high sensibility of the fail mode to local defects, the results obtained in the fatigue curves can be much spread. The simulation of the fatigue, even if it is performed and is available in some software programs, required a deep knowledge of the problem and the performance of the material as well.

It is important to remark that the evaluation of fatigue efforts must include effort concentration effects, applicable to corners, reinforcement ribs, etc. On the other hand, as the plastic sheet is generally subject to fatigue with a low deformation but high cycle times, a linear effort analysis could be precise enough. In the case of simulations of finite elements, a mesh sensible to curvatures in the reinforcement ribs is also recommendable.

5 Creeping

All plastic structures suffer of creeping, and usually a deformation creeping limit is set for any product. This deformation ϵ_{all} , must be less than the deformation to the rupture at the end of service life T. A very conservative protection can be reached by selecting a proper design effort given by: $\sigma = \text{Min}(\sigma_1, \sigma_2, \sigma_3)$, wherein:

σ_1 : (effort caused by a deformation of ϵ_{all} at the end of life time T) / $(SF=10)^3$.

σ_2 : (effort caused by the appearance of cracks at the end of time T) / $(SF=1.0)$

σ_3 : (effort caused by the rupture at the end of time T) / $(SF=1.5)$.

³ Usually, this is the criteria applied on the design of containers by the technical staff of Polinter as support of its customers.

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The short-term deformation terms, as well as effort criteria are implicit in these expressions, but it is not for short or long-term efforts. Therefore, more sophisticated tools must be applied, such as simulators.

A SF= 1.0 for σ_1 and σ_2 is assigned as the part will not catastrophically fail once reached the allowed deformation; in this case, the product may be retired without any damage. However, the rupture by creeping denotes a catastrophic fail and in this case a SF= 1.5 is necessary.

It is important to mention that the showing of cracks and the rupture are found in areas in which high concentration of efforts are present. Thus, the designs that must fulfill these requirements must be those that the efforts, including their concentration effects, are less than the aforementioned σ . These criteria are applied in elements of local design, such as reinforcement nerves, interfaces with metal inserts, etc as wherein the mechanism of fracture probably begins to work.

6 Constant Thermal Efforts

From the point of view of thermal efforts, it is not necessary to add an additional SF to design a part. It is just necessary to use proper design criteria (such as to impede the thermal expansion or contraction) to minimize. On the other hand, it is recommendable that the sum of the thermal and load efforts to be less than 80% in the short-term fluency.

The reason why is not required to place an SF, is that in the first place, these thermal efforts are very low in plastics, and in second place is that these efforts tend to relax along the time. Expressed in percentages, the speed of relaxation of thermal effort is approximately equal and opposed to the speed of creeping. Therefore, it not possible a catastrophical failure of the material merely due to the action of thermal efforts, either in the long or short term.

7 Thermal and Creeping Cycles

There are many plastics that undergo through relatively regular load / unload cycles, and in many times these include thermal cycles. In this way, the part passes through creeping and recovery cycles according to the relation effort – creeping – time – temperature of the material.

Usually the effort acts at a high temperature, and the relaxation at room temperature. This situation is delicate as the speed of deformation under creeping and temperatures is high, while the recovery speed under room temperature is somewhat slow (as well as creeping in room temperature), whereas the deformation by creeping is not wholly recoverable, and in each cycle is accrued certain amount of residual deformation by creeping that is not recoverable in high-effort places.

The unique limit set forth in terms of design is that $\epsilon(T) \leq \epsilon_{all}$, wherein $\epsilon(T)$ is the accrued deformation at the end of the lifetime of the part T, and ϵ_{all} is the allowed deformation for the material. However, determining the effort or accrued deformation per cycle is not an easy task.

8 Periodical Vibration

Periodical vibration is related with an identifiable excitation force that generally is from a rotating machine, such as hand tools. Plastic components subject to vibration must be rigid enough such as its natural frequency (FN) is at least 2.0 times bigger than the rotating frequency of the machine. This value is assigned when $FN > 2.0$, efforts in dynamical conditions are less than those in static conditions.

If there is more than an excitation frequency coming from a rotating machine, it is recommended to use simulation tools given the unfeasibility of designation of a FS specific value.

9 Random Vibrations

Random vibrations are obtained when a wide array of excitation frequencies is present all the time, so it is not possible to design a particular frequency. The

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following indicators may be used as a guide to design the part:

- Apply high rigidity, enough radiuses of edges, proper methods of assembly of parts, and control processes that minimize the residual efforts. Jointly, this will reduce the response of the effort.
- Include additional support points or additional mass.
- It is acceptable that in the calculation of the natural frequency and the modal analysis, to ignore the nerves as they turns into conservative estimates of efforts.

A high resistance in the material will also increase the frequency values of resonance, therefore (fortunately) energy values are less.

A real random vibration example is what car windshields suffer when they are raised. As reinforce nerves cannot be added, all the rigidity must come from the shell-shaped window, as well as from the support methods thereof.

If simulation tools are used to analyze these cases, it is recommended the use of highly detailed models, and finely discreet in order to detect small sources of concentration of efforts that might act as acceleration elements of failures. However, computer, memory and time costs are high.

10 Buckling



Buckling occurs when compressive resulting efforts, combined with a buckling effect, are predominant in certain parts of the component (see figure).

In order to prevent buckling, is required to increase the rigidity of the part, as the

three components that provide rigidity to the part are important in order to avoid this effect: the module of the material, the thickness of the part and the reinforcement design elements such as nerves.

A $FS=2.0$ is generally applied on the buckling critical load, which is also calculated by a non-linear buckling analysis. In other words, the minimum buckling resistance of the part must exceed by two the applied load. The only way to achieve this is by increasing the thickness, amount and height of the ribs, as well as to increase the number of supports. These analyses may be provided by the Staff of Technical Services of Polinter.

As they are low-rigidity materials, almost all plastic structures are very prone to fail due to buckling. On the other hand, many processes for plastics, limit the value of thickness of the part, thus generating a lack of rigidity that avoids buckling; so the design elements are required to avoid this failure mode.

Other well-known factors such as the eccentricity of the load, the non-uniformity of properties, thickness and non-linear behavior of the material, tend to reduce the resistance of the material to buckling. On the other hand, it must be recognized that for any given material or part there are no natural effects that increase buckling resistance; just proper design elements may increase such resistance.

Until now, we have seen the considerations inherent to an effort analysis as stage in the process of design of a plastic part, and it is important to bear in mind that all proposed conditions are intended to the **survival** of the designed part to certain loads or deformations without failing. In any case is required that the part failed or flow somewhat. However, there is new design criteria for applications in which are required that the material collapses due to efforts, as it will be explained herein below.

11 Thickness Limits and Use of Reinforcing Elements

The distinctive aspect of all plastic designs is that the manufacture process imposes a limit of

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thickness to the parts. It seems that a maximum universal limit of 15-20 mm is applied to all plastic, regardless of the process. On the other hand, for most of the plastic parts, the lengths and width are considerably bigger than thickness. This is the reason why reinforcement elements are needed when the ribs are designed:

- It is recommendable to achieve a greater rigidity by placing more nerves than less quantity of nerves with a larger height. This is due that besides enduring the tips of the nerves to greater conditions of efforts, the nerves of larger height generate torsion buckling problems under eccentric loads.
- A reduced number of nerves of larger height provide rigidity only when efforts are high, but decrease the weight of the part. On the other hand, a larger amount of nerves with less height provides the same rigidity at a reduced level of efforts, but with a bigger weight of the part.
- It is recommendable to place nerves in two perpendicular directions, even if the design does not strictly require them in the second direction.

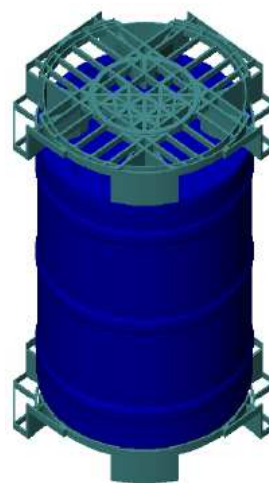
The geometrical design of a reinforcement nerve if commonly obtained from the extrapolation of previous successful designs, and generally there are no specific rules for a more efficient design. There must exist a balance between the thickness of the part imposed by the process, the nerve height imposed by the permissible effort, as well as achieving both weight and rigidity requirements.

Other physical reasons that complexes the design of nerves are: (i) generally are applied on curved surfaced; (ii) Its height is not constant and the tip might be shaped; (iii) It could be partially slotted due to packaging reasons; (iv) It could have a hole for insertion; (v) are spread in an non-uniform way. Due to these difficulties in achieving a design pattern, it is recommendable to exceed the required rigidity in the initial design and thereafter verify by applying simulation tools.

Although nerves and other reinforcements might considerably increase the rigidity of a part, the geometrical styles of nerves depend on the process to be used. Here are some aspects related to the rigidity of the part, depending on the molding technique employs:

- Molded parts by injection might be designed for a desired flexing rigidity, but in general they are deficient in terms of torsion rigidity due to the presence of open nerves (visible).
- Gas-assisted processes produce hollow nerves that might increase both flexing and torsion rigidity. However, the process allows the placement of few nerves in the pre-selected locations. On the other hand, these hollow nerves cannot be intercepted and it must be considered that the method of assisted injection by gas is applied for the manufacture of relatively large parts.
- Molded products by rotomolding or double layering in which two opposed surfaces are designed to be in contact and merged have a high flexing and torsion rigidity.
- Bottles molded by blowing, as well as drums and containers have a high rigidity due to its geometry, which (generally) is round.

12 New Concepts in the Design of Plastic Parts



The low rigidity of plastic materials compared to that of metal is not a disadvantage as there have been developed new design concepts and elements upon this property. Among the newest properties, we can find the "snap fits" that are used in removable or non-removable packages, and that might be integrated

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in a part. These elements could not be added in materials such as metal, and represent a great advantage with a reasonable cost and less amount of material.

In second place we find the concept of consolidation of the part, it means, the possibility of combining in a single final part. In the case of metals, many separated parts had to be joined, which implies more time, costs and production challenges.

Finally, there are those applications wherein thanks to a low modulus and a high capacity of deformation of materials, there have been developed almost-unbreakable parts with a high resistance to impacts. Considering these aspects, there has been an important development of a wide array of products based on the concept that the part must fail under certain loads. The best examples are medical products and hygienic packages. Lids of dairy products, for example, milk may protect the contents of the bottle if falls to the floor, but it can be broken easily when the correct

load is applied, for example, when opening the package.

Other unique functions have been achieved with plastics, which are:

- Energy-absorbent articles, soundproof panels and vibration dampers that take advantage of the visco-elastic properties of the materials;
- Support elements widely used in anti-seismic support systems, by using a visco-elastic gel that is forced through small orifices in which a piston is placed and the gel passes through the piston at a very low speed, but they clog and solidify if high speed caused by seismic is exhibited.
- Materials with either high or low friction coefficient, which are widely used in home applications.
- Impact-resistant materials, such as application that stop bullets at high speed.

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Main characteristic of behavior		SF	SF Applied on...
1	Resistance, Rigidity	1.5	Fluency effort, maximum deflexion allowed.
2	Non-linear behavior	1.5 [E_{tan}/E_{sec}]	Fluency effort, maximum deflexion allowed.
3a	Fatigue	10	Number of cycles allowed
3b	Fatigue	2	Endurance Limit
4	Resistance to Creeping Life = T hours	Apply design effort: =Min($\sigma_1, \sigma_2, \sigma_3$), wherein: σ_1 : (effort caused by a deformation of ϵ_{all} at the end of life time T). σ_2 : (effort causing crazing at the end of time T). σ_3 : (effort caused by the rupture at the end of time T)	
5	Thermal Effort	1.5	Total effort due to mechanical loads and thermal efforts
6	Periodic Vibration	2.5 ~ 3.0	Forced frequency
7	Random Vibration	Hard to predict, it is recommended the use of specialized help if it is the predominant factor of behavior of the part.	
8	Buckling	2.0	Required Buckling Resistance. Apply non-linear buckling analysis.
9	Failure Design	≤ 1.0	Detailed analysis by means of simulations. Product Trial.

This bulletin has been elaborated by the Marketing Management of Polinter, with the support of specialists of Investigación y Desarrollo, C.A. (INDESCA), and the Technical Services Management of CORAMER. It is intended to all the users of Venelene resins and we trust that the information herein contained will be useful. In case of comments or suggestions, please write to info@polinter.com.ve or contact our Commercial Agent at <http://www.coramer.com>

The information described in this document is, to our best knowledge, accurate and truthful. However, since the particular uses and transformation conditions are completely out of our hands, the adjustment of the parameters in order to reach the maximum performance of our products for a specific application depends on and is the responsibility of the user.

For further information on safety features and the handling and disposal of our products, please consult the Safety Data Sheet (MSDS) of Venelene Polyethylene.