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Silolarda Kullanılan Elevatör Kovalarının Maliyet ve Mukavemet Açısından Ashby Metodu ile Optimizasyonu

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ÖZ

Silo sistemleri hububat depolamak için kullanılan yapılardır. Genellikle silindirik ya da dikdörtgen şeklinde olup metal, beton ya da tuğla gibi malzemelerden inşa edilirler. Silolar, taşıma, havalandırma ve tahliye gibi alt sistemleri içerebilmektedir. Elevatörlerdeki kovalar, çeşitli tahıl türlerini taşıyan, taşıma sistemi parçalarından biridir. Bu çalışma, kovalar için maliyet ve mukavemet açısından optimum, farklı iklimlerde kullanılan ve enjeksiyon kalıplamaya uygun malzemenin seçilmesini amaçlamaktadır. Bu doğrultuda, Çukurova Silo Firmasında saatte 80 ton buğdayın taşınmasında kullanılan özel bir kova türü incelenmiştir. Tahıl taşıyan kovalara uygun malzeme seçimi için Ashby yöntemi olarak adlandırılan ileri malzeme seçme tekniği uygulanmıştır. Taşıma esnasında kovada oluşan gerilmeleri bulmak için ANSYS® Mechanical kullanılmıştır. Aday malzemeler özelliklerine göre kıyaslanmıştır. Kova üretimi için bazı malzemeler belirlenmiştir. Son olarak, belirlenen malzemeler ANSYS® Mechanical sonuçlarına göre karşılaştırılıp özel tip kova üzerinde analiz edilmiştir. Sonuç olarak cam elyaf katkılı PA6, optimum malzeme olarak belirlenmiştir.

Application of Ashby Method for Optimization of High Strength, Low Priced Bucket for Silo Elevators

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ABSTRACT

Silo systems are used to store the bulk grain. In general, they are constructed with cylindrical or rectangular shape with steel, concrete, or brick materials. Silos may have subsystems for operation such as transportation, aeration, and discharge. Buckets in elevators are one of the major parts of transportation system which carries various kinds of grains. This study aims to select the optimum material for buckets in terms of strength and cost which are suitable for injection molding that are used in different climates. For this purpose, in Çukurova Silo Company, a specific type of bucket being used for the transportation of 80 ton of wheat per hour was analyzed. To choose the suitable materials for buckets that carry grains, advanced material selection technique, which is called as Ashby method, had been applied. ANSYS®

Mechanical was used to find out stresses during the carriage of the grain. Candidate materials were ranked with respect to their properties. Some materials were determined for the usage of production of the buckets. Finally, the materials were compared with respect to the ANSYS® Mechanical results and tested for this specific type of bucket. As a result, PA6 with fiber-glass variant was chosen as optimum material.

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1. Introduction

Bucket elevators are motorized conveying equipment consisting of a continuous belt or chain to which buckets are attached for carrying bulk items in a vertical or severely inclined course. Due to the flexible belt/chain, the buckets travel unidirectional within a casing, collecting bulk items at the bottom end and delivering them at the top end, (Patel et al., 2008).

Elevators consist of four components:

1) Buckets to carry the bulk grain.

2) A belt to transport the buckets and transfer the pulls.

3) Means to operate the belt.

4) Attachments for loading buckets or scooping up material, collecting discharged material, regulating belt tension, and enclosing and safeguarding the elevator.

Almost all centrifugal discharge elevators feature rounded bottomed spaced buckets. At the foot pulley, they pick up their load from a boot, a pit, or a mound of material. The buckets can also have a triangular cross shape and be placed close together on the belt with little or no clearance. This is called as a bucket elevator that runs continuously. Its primary use is to transport tough materials at a slow rate. A flat chain with buckets connected every several inches was utilized in early bucket elevators. A rubber belt with plastic buckets is now in use. An example of the bucket elevator and its components are given in Figure 1.1.

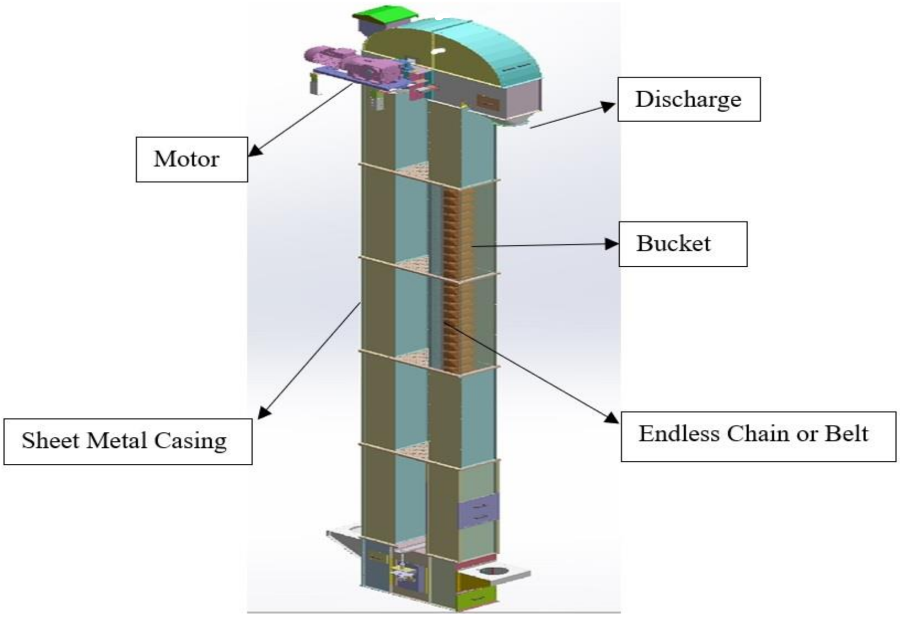


Figure 1.1. Main parts of elevator conveyor.

A wide variety of material can be a candidate for the production of buckets. Suppliers for the industry are constantly introducing new technical materials. Engineers now have a large variety of materials to choose from 160.000 or more (Ashby, 2011), therefore engineers have to choose optimum and suited materials for their purpose. Advanced material selection method should be used before starting a particular design process. A methodology suggested by Ashby is an advanced material selection approach that generates material charts to find the optimum material for a certain target function, such as increasing strength while minimizing cost or increasing strength while decreasing weight of an object. When this method applied, it provides direction and greatly simplifies the first screening of possible candidate materials. Ashby method was used in several subjects such as High Strength and Lightweight Spur Gear Design (Delibaş et al., 2017), Materials Selection in Micromechanical Design (Srikar and Spearing, 2003). The methodologies are easily implemented as computer-based tools, one of which is the Granta CES Edupack materials selection platform. The Ashby technique considers all material characteristics, including mechanical, physical, optical, and thermal ones (Ashby, 2011). In addition to that, CES Selector is one of the most powerful tools for material selection since it can rank materials based on their material index or indices value, which may be derived using the Ashby approach. Indices that consider tooth form provide a tool for enhancing material co-selection (CES Selector, 2016). One property does not determine performance, it is almost always a mix of traits that is important. As an example, requirement for high strength at a low weight can be given. Performance is limited by material attributes. Machine member designs that are lightweight and low cost are becoming increased by using Ashby's technique. This research aims to select low-cost and high strength materials for certain bucket design that is suitable to use in cold climates which can reach down to -50 ºC by applying Ashby method together with material selection software which is CES

Edupack. The restriction was established as bending or fracture failure criterions and shear failure, with the target function being to reduce the bucket's cost with increasing bending strength, fracture toughness and shear strength. To be able to find candidate materials, Ashby chart was applied and material index value was rated using the CES Selector tool for a specific bucket which is used to transport 80 ton grain per hour. Following the selection of candidate materials, a variety of ranked materials were tested for a specific bucket. The results after material changed were compared with each other based on finite element analysis. This method is widely used in engineering research and applications based on its approach and validity compared to actual design. Computer Aided Numerical Damage Analysis of the Axle Shaft (Adin et all,2022) and Finite Element Analysis of Safety Pin in Snowplow Equipment (Adin et all., 2022) can be given as examples where finite element analysis were used for static structure analysis. It is efficient way of analyzing and visualizing the behaviors of designed parts in different conditions. In this study ANSYS® Mechanical was used as FEA software.

2. Material and Methods

Different types of material selection procedures, such as choice matrix, PUGH method, analytic hierarchy process (AHP), and others, are accessible in the literature (Dieter et al., 2009). When the approaches' efficiencies are compared, it is clear that the Ashby methodology outperforms the others. Because, in contrast to Ashby's technique, the above-mentioned evaluation methods need experiment and personal judgment. To analyze the prospective materials, the engineer must establish the appropriate weight factors. In the Ashby material selection technique, however, simply employing the required design formula is sufficient to discover the optimum material for the proposed product. Furthermore, because the determination of the material index is parametric research in the Ashby method, the material index of each material is correct and there is no dispute.

2.1. Advanced Material Selection (Ashby Method):

In Ashby method translating the design requirements is the basic step to select the optimum material. It basically includes the following steps:

1-Function: It is the answer of "what does a component do". In this case, Bucket to transport grains for high elevations is suitable for function.

2-Constraint: Constraints are the nonnegotiable conditions to be met. There are two kinds of nonnegotiable constraints must be met, soft and hard constraints.

3-Objective Function: Objective is the aim which is desired to increase or decrease for the material. In our study, objective was chosen to minimize the price, as it is not preferred to cost much more than the cost of the production of the previously used buckets. For this reason, it is desired to choose the one with the low-price as well as meeting the constraints.

4-Free Variables: Free variable can be defined as what the designer is free to change. (Ashby, 2011). In this study shape of the bucket and other variables are constant except material choice. So, material selection is free variable.

For this study the simple Ashby Diagram chart that was created for the selection of appropriate bucket material is given in Table 2.1.

Table 2.1. Ashby translation chart

Ashby Translation Chart
Function: Bucket to carry grains for higher elevations.
Constraints: Must be safe for food contact Must have high yield strength Must have high fracture toughness Must have excellent injection molding capability. High surface hardness required against grains that touches to the surface of the bucket Minimum service temperature should be suitable for cold working conditions.
Objective Function: Minimizing the price
Free variables: Material Selection

2.1.1. Material Index

A performance equation is used to determine components' performance. The material qualities are organized into three groups (Functional Requirements, Geometric Parameters and Material Properties) in the performance equation as it is seen in Figure 2.1. The property that maximizes performance for given design is material properties called as material index. They provide criteria of excellence that allows ranking of materials by their ability to perform well in the given application. Material index provides the selection of optimum material between the materials ranked with respect to constraints (Ashby, 2009).

$$P = [\binom{Functional}{Requirements, F}, \binom{Geometric}{Parameters, G}, \binom{Material}{Properties, M}]$$

Figure 2.1. Material performance

In our study the objective function was to minimize the price. Each of slice that bolt effect was the same so that three slices were taken on the bucket to find out material index. Material index was the same for all other slices shown in Figure 2.2.

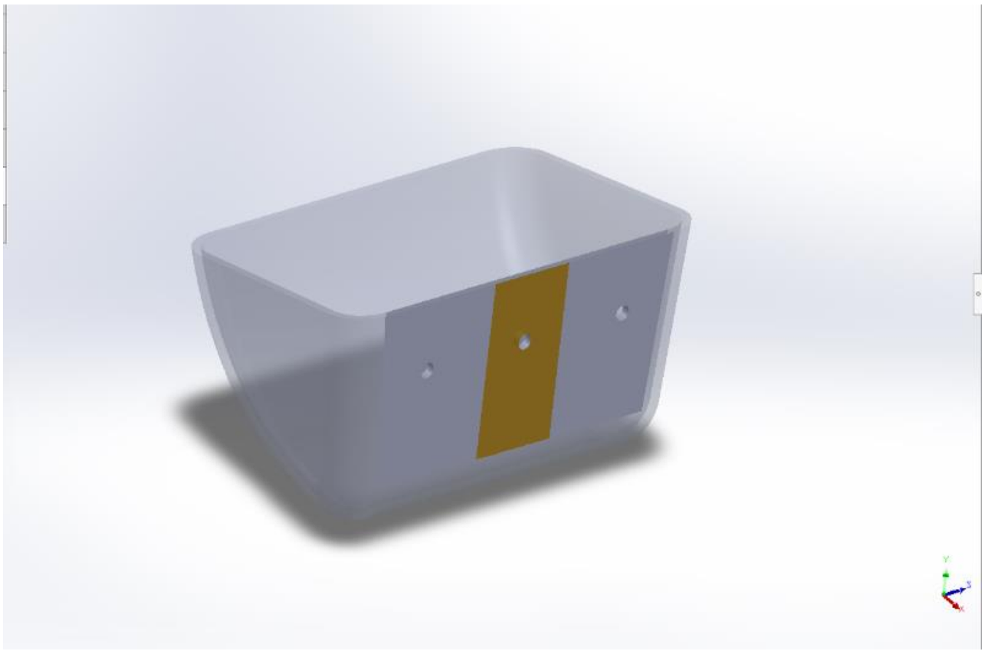


Figure 2.2. Bucket used for 80 ton/hour in CSI

The thickness of section part shown in Figure 2.2. is 6 mm and width is 60 mm.

$$C=C_m pAL \tag{1}$$

In this formula C is the material cost that is calculated by equation (1). C_m is the cost of the material to be used per unit weight and p is the density of the material. A is the cross-sectional area of the slice shown in Figure 2.2. L is the length of the cross section shown above.

$$I = \frac{bh^3}{12} = \frac{10h^4}{12} \tag{2}$$

I is the moment of inertia and b is the width of the plate and h is the thickness of the plate.

$$Width = 60mm$$
$$Thickness = 6mm$$

$$\sigma = \frac{Mc}{I} = \frac{M\frac{h}{2}}{\frac{10h^4}{12}} = \frac{6M}{10h^3} \tag{3}$$

In equation (3), σ is stress, M is bending moment, c is the outermost perpendicular distance from neutral axis to surface.

$$Area = bh = 10h^2$$

$$A = \left(\frac{6M}{\sigma}\right)^{2/3} \quad (4)$$

$$C = C_m\rho\left(\frac{6M}{\sigma}\right)^{2/3} L \quad (5)$$

$$C = (6M)^{2/3}\ L\ \ \frac{C_m\rho}{\sigma^{2/3}} \quad (6)$$

Material index to be minimized is M = $\frac{C_m\rho}{\sigma^{2/3}}$.

By using equations 1-6 the material index is found. The necessary calculations are made in order to have a result to find material index by calculating each component that is necessary to find out.

These equations were written by considering the bucket as a beam with high strength as it is subjected to the bending stress mostly.

2.2. Grain Weight

The total volume of the empty space that bucket can carry grains was found as 4.9 liters as shown in Figure 2.3. The bulk density of wheat was taken as 830 kg/m^3 by considering the information taken from Cukurova Silo. So, the total amount of wheat that can be carried is 4.06 kg. The whole body was thought as full of its carriage capacity, as result 4.06 kg wheat is carried and as force is equal to 39.82N (~40N). The technical drawing of the bucket is shown in Figure 2.4.

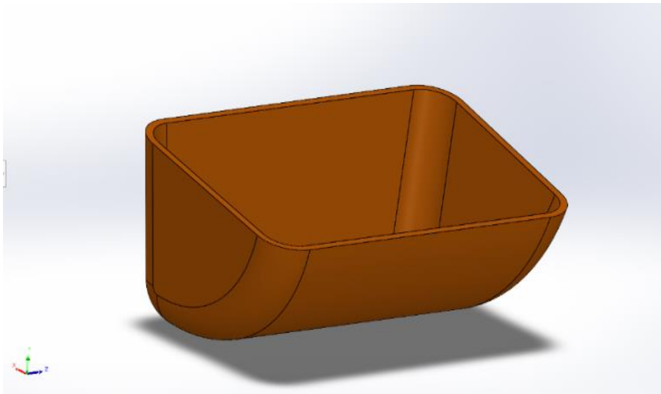


Figure 2.3. Empty volume that grain can be filled

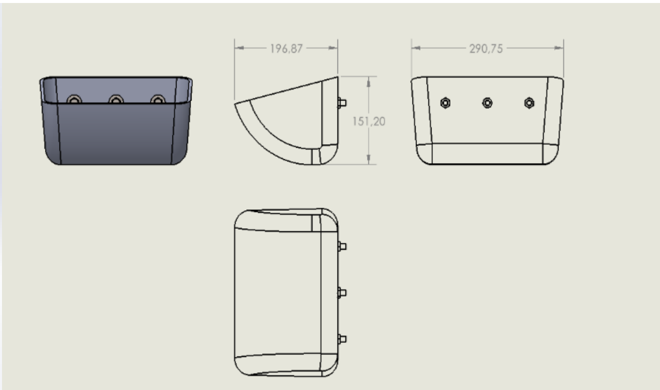


Figure 2.4. Technical Drawing of the Bucket

2.3. Finite Elements Analysis:

Finite element analysis (FEA) is a widely used tool in engineering application for analysis. It can be used for the applications of structural, fluid flow, energy transportation such as heat transfer and so on.

It is practical and trustful approach to observe the results for demanded application in engineering. To find out the stresses applied to the bucket, whole body was analyzed in ANSYS® Mechanical. Analysis and validation of Eicher 11.10 chassis frame using Ansys (Patel et all, 2013) can be given as a good example for the validation in between real case and simulated results. The result of this study is very close to the real conditions. In our case the outside temperature was selected as -40 ºC while inner side of the elevator was selected as -30 ºC by considering cold climate working conditions and thermal shock caused by the temperature difference. Weight of the grain that the bucket can contain was applied as force together with gravitational acceleration beside of the acceleration that a bucket can come across in elevator while transporting grain. Bolt connections were accepted as fixed geometry in ANSYS Mechanical modeling. Boundary conditions can be seen in Figure 2.5. For the analysis of the bucket, the weight of grains that the specific type of bucket carries to higher elevations must be determined by using the density of bulk grain and the empty volume of the bucket that grains fill inside. For this purpose, Solidworks software was used to determine the empty volume for grain transportation.

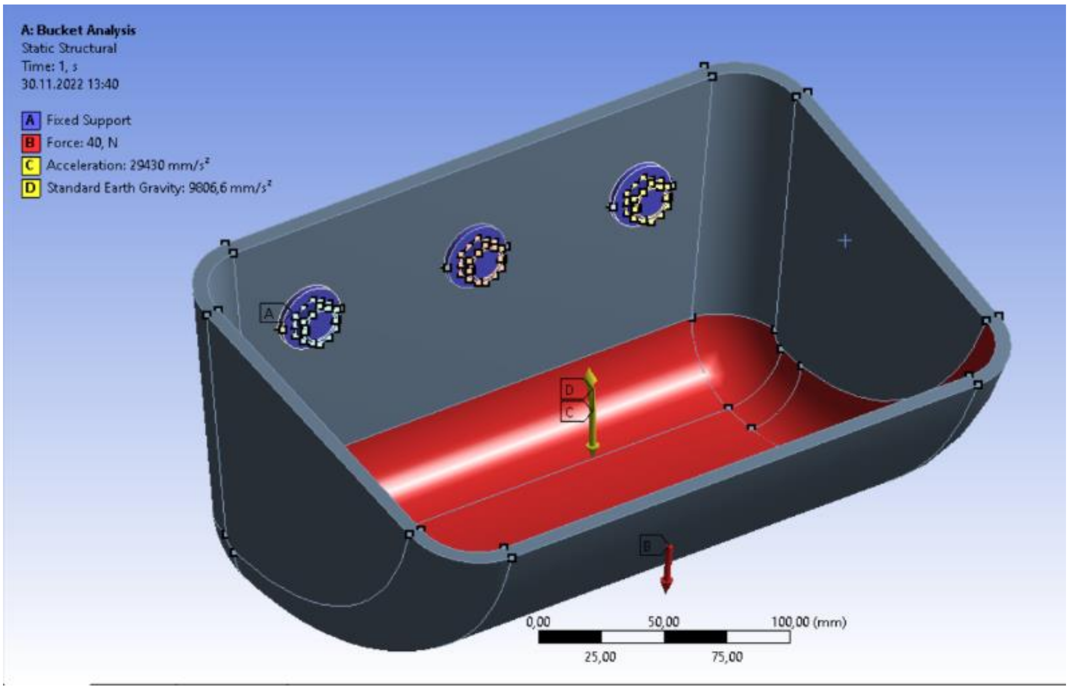


Figure 2.5 Boundary conditions of static analysis

2.3.1. Mesh Generation in ANSYS® Mechanical

ANSYS® Mechanical program was used to analyze the results of stresses occurred in bucket. For a reliable result meshing must be done properly. Mesh quality can be determined with respect to some major concepts shown in Table 2.2. Mesh quality values.

Table 2.2. Mesh quality values (ANSYS Mesh Quality and Advanced Topics Lecture 7, 2015)

	Excellent	Good	Acceptable	Inacceptable
Skewness	0-0.25	0.25-0.80	0.8-0.94	0.98-1
Aspect Ratio	1	1-5	5-10	20
Orthogonal Quality	1-0.95	0.95-0.2	0.20-0.15	0-0.001

In the analysis of the bucket fine mesh was created with a 100% relevance. Local mesh sizing applied where the force effects are seen mostly on the bucket. These are the regions where bucket and bolt contact with each other as most of the stresses occur at that region. Total number of elements in the mesh is 1863424 and total number of nodes is 2774175. Average aspect ratio is 1.86, skewness is 0.22, and orthogonal quality is 0.77. The mesh of the bucket can be seen in Figure 2.6.

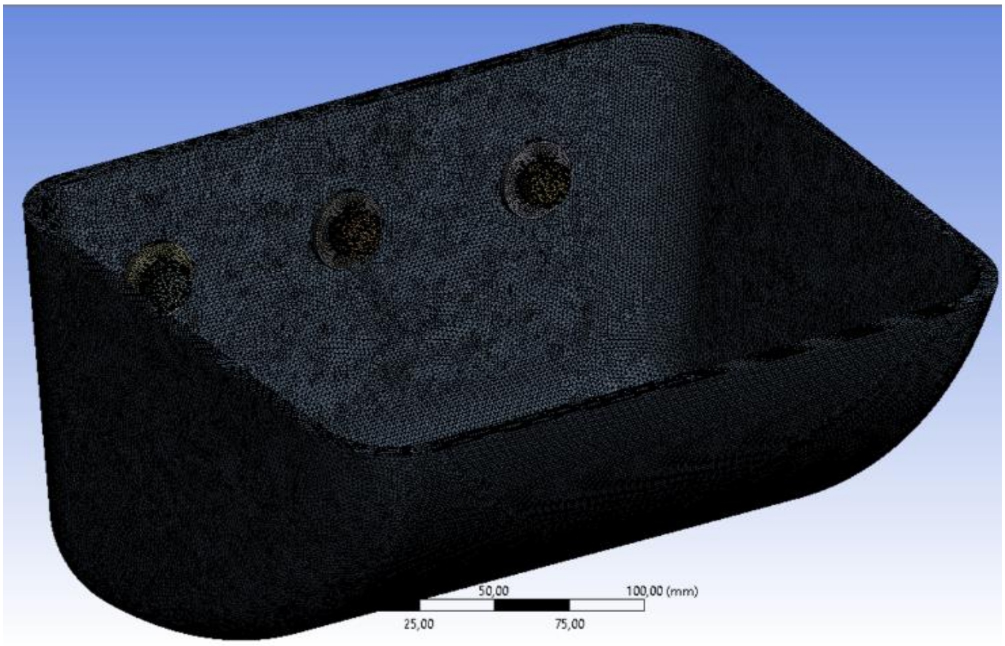


Figure 2.6. Mesh generation

2.4. Fracture Toughness:

Fracture toughness is another important criterion to be found out beside of stresses occurred during the transportation of grains. For a bucket some cracks or flaw propagation can be seen by the time. Mostly these propagations occur at the connection points of the bolts and bucket as high stress effects seen in these regions mostly.

$$K_I = \beta\sigma\sqrt{\pi a} \tag{7}$$

$$\frac{K_{IC}}{K_I} = n \quad (8)$$

β is stress intensity modification factor. σ is stress value which is taken from Ansys results. a is the length of the crack that is allowed to occur. K_I is stress intensity factor and K_{IC} is critical stress intensity factor.

3. Results and Discussion

In our study, lots of properties were taken into consideration, such as maximum stress that buckets can handle with respect to safety factor of 1.5 at least, also fracture toughness with respect to 2 mm crack propagation as maximum at the edges of the bolt holes. As production method, in general injection molding is used for plastic materials. That's why bucket material must have excellent injection molding process capability. During the loading and unloading of the grains from the bucket, surface of the material is exposed to the friction, and it causes erosion on the surface of the bucket. Especially small sized and sharp-edged grains, such as wheat, may give damage to the surface of the bucket during loading and unloading. That's why high hardness is necessary as soft constraint, and this property provides long term usage without erosion and crack propagation because of friction of the grain. Some of the bucket elevators that are produced in Çukurova Silo Company, work at cold climate conditions. It may cause some problems such as decreasing impact toughness. That's why it is also necessary to withstand cold climates for a bucket. So that, working temperature condition was set up as -40 ºC degree or more to analyse in Ansys Mechanical. But as coldest working conditions can be observed as -50 ºC degree with respect to information taken from Çukurova Silo Company. Applying Ashby method by using CES Software Application, different candidate materials were ranked depending on constrains mentioned above. Candidate materials were analyzed in ANSYS® Mechanical and results were compared with HDPE material which is currently in usage to produce buckets.

TABLE 3.1. Ashby translation chart

Ashby Method Translation Chart
Function; Bucket to carry grains for higher elevations.
Constraints; Must be safe for food contact Must have high yield point Must have fracture toughness at least 3.68MPa$\sqrt{m}$ for in case of HDPE used for bucket. Must have excellent injection molding capability. High surface hardness against grains damage to the surface Minimum service temperature should be at most -50 Celsius degree.
Objective function ; Minimizing the price
Free variables; Material Selection

3.1. CES Software Application

A distinctive collection of instructional tools, Granta CES EduPack supports the use of educational materials. Granta EduPack offers assistance to improve undergraduate course materials instruction. A database of knowledge on materials and processes, tools for selecting items, and a variety of supplementary resources are all included in CES EduPack. A lot of different materials exist in engineering. Ashby charts provide to compare them with different aspects such as yield strength-price or yield strength-density and many more. CES Edupack software provides useful tool to implement Ashby methodology to the charts to select the optimum material together with applying constraints to be met. When the constraints and material index applied to the chart, candidate materials to be ranked seen on the chart. In our study Ashby translation chart was determined in Table 3.1. The constraints applied to the CES Edupack Software and as the aim of this study was to find out the optimum material in terms of yield strength-price, Ashby chart was set to the yield strength-price. Material index found in section 2.1.1. applied to the CES Edupack shown as line with a slope of 2/3 in Figure

3.1 and materials on this line performs equal to each other. Materials located above this line, outperforms to others. Between defined engineering materials, CES Edupack restricted the materials that are not suitable shown as gray dots and suitable materials represented as red dots shown in Figure 3.1.

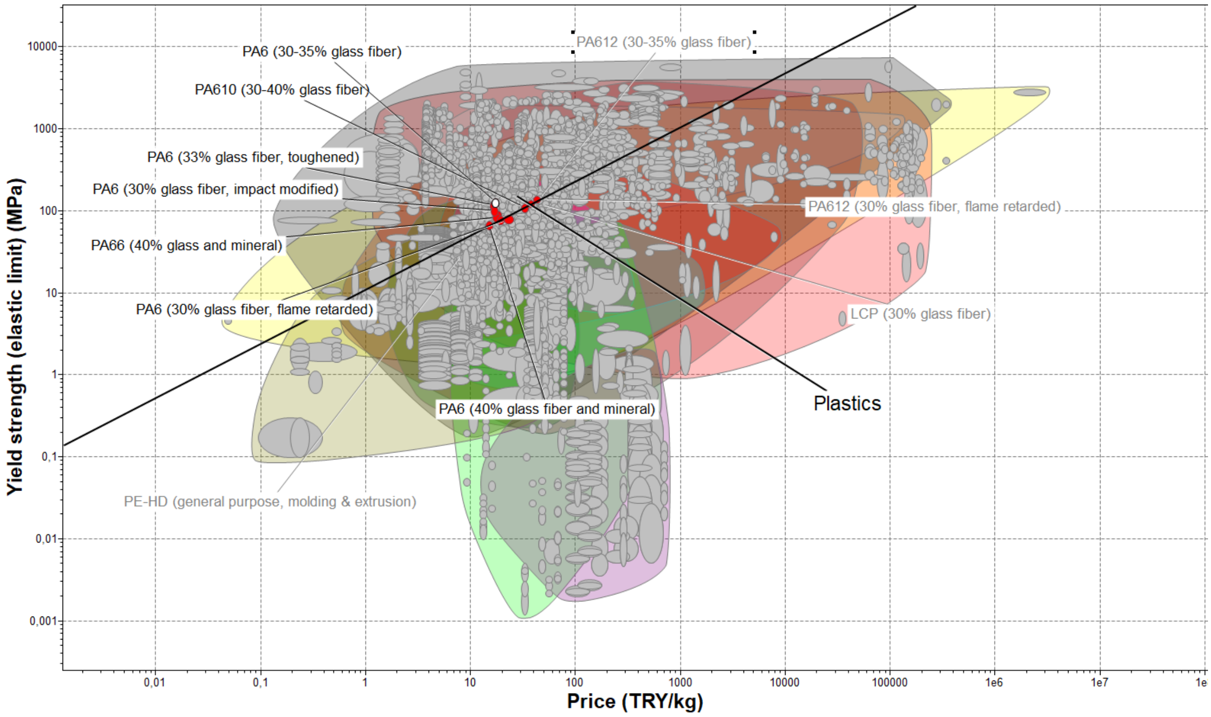


Figure 3.1. Yield strength-price chart

After restriction possible materials were selected to be ranked to find out the optimum one among the other candidates. These materials are labelled in Figure 3.1. and the comparison of them was tabulated in Table 3.2.

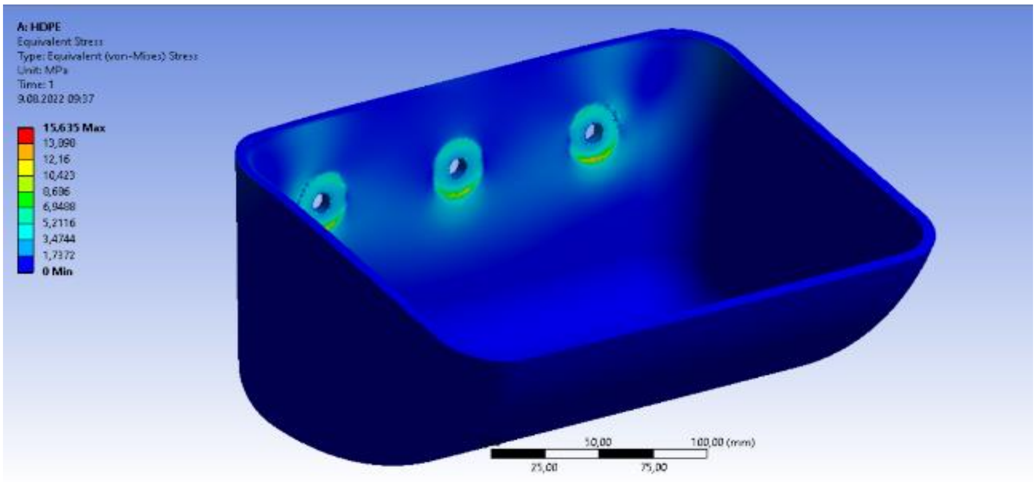
Table 3.2. Materials to be ranked (CES Selector, 2016)

Material	Density($\frac{kg}{m^3}$)	Tensile Strength(MPa)	Young's Modulus (GPa)	Yield Strength (MPa)	Specific Stiffness (MN.m/kg)	Hardness (Rockwell-R)	Fracture Toughness (MPa.M^0.5)	Toughness $\frac{kJ}{m^2}$	Impact strength (At -30 C°)
PA6 (30%-35% Fiberglass)	1340-1360	108-132	5.34-6.66	111-139	3.95-4.93	158-175	4.39-4.85	3.09-4.12	6.9-15
PA6 (33% Fiberglass toughened)	1350-1380	104-128	6.34-7.91	103-129	4.64-5.8	156-172	4.55-5.03	2.8-3.74	9.61-20.9
PA66 (40% Glass and Mineral)	1450-1480	74-91	5.11-6.38	74-92.3	3.49-4.36	132-146	4.35-4.81	3.17-4.24	2.29-4.98
HDPE (General Purpose)	952-965	22.1-31	1.07-1.09	26.2-31	1.11-1.14	45-55	1.52-1.82	2.15-3.04	3.33-16.3
PA 610 (30%-40% Fiberglass)	1330-1360	115-140	5.74-7.16	97.9-122	4.27-5.33	163-180	4.46-4.93	2.97-3.96	***
PA6 (30% Fiberglass Impact Modified	1290-1310	89-110	4.74-5.91	88.7-111	3.65-4.55	145-160	4.29-4.74	3.33-4.44	9.61-20.9

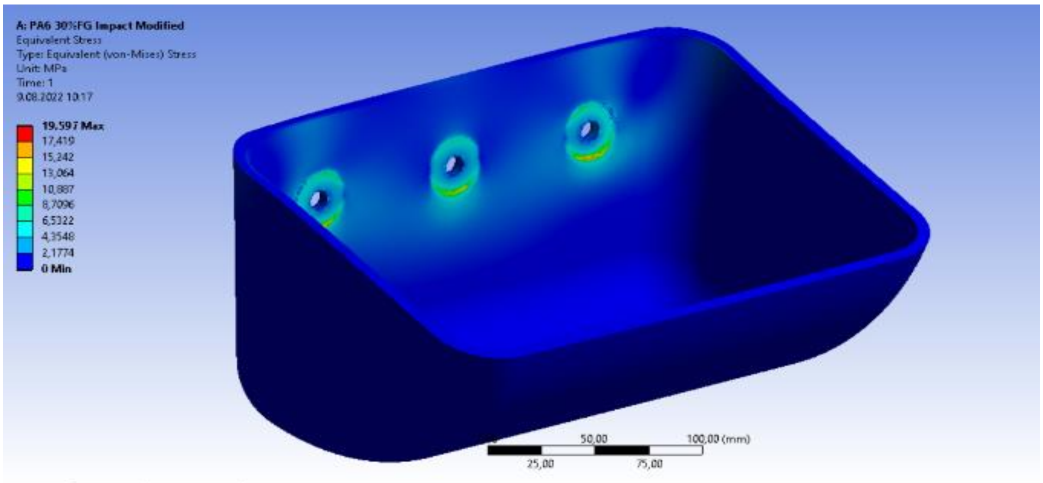
3.2. FEA Results

3.2.1. Equivalent von Mises

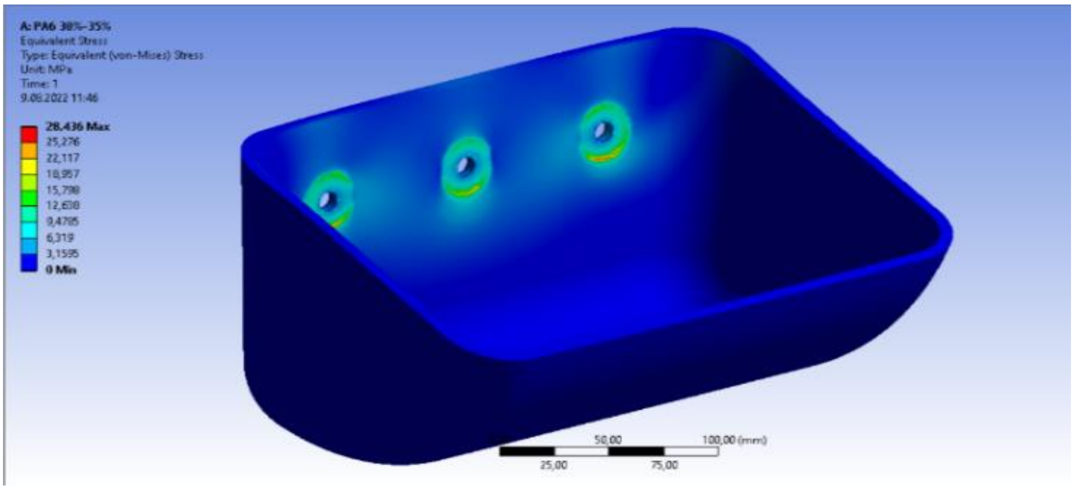
Von Mises found that, even though none of the principal stresses exceeds the material yield stress, yielding is still possible because of the combination of the stresses. The von Mises criterion is a formula for combining the three main stresses into an equivalent stress, which is then compared to the material's yield stress to determine the material's failure state. As a shorthand for the comparable stress, it is frequently referred to as the von Mises Stress (Qiang and Yong, 2014). For the loads applied to the bucket by grain to the bottom surfaces, the von Misses Stress value is maximum 15.635 MPa which is located just behind of the washer for HDPE material seen in Figure 3.2.a. In other regions the effect of the load caused by grains are negligible. For PA6 30% fiberglass impact modified and PA6 with 30%-35% Fiberglass materials stress values are 19.597 MPa and 28.436 MPa as they are seen in the Figures 3.2.b. and 3.2.c. with order.



(a)



(b)



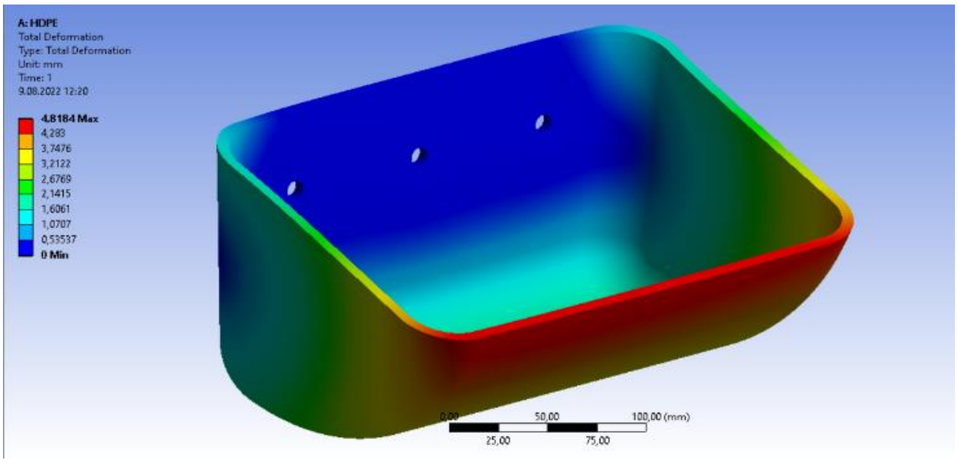
(c)

Figure 3.2. Equivalent von Mises Stress values for

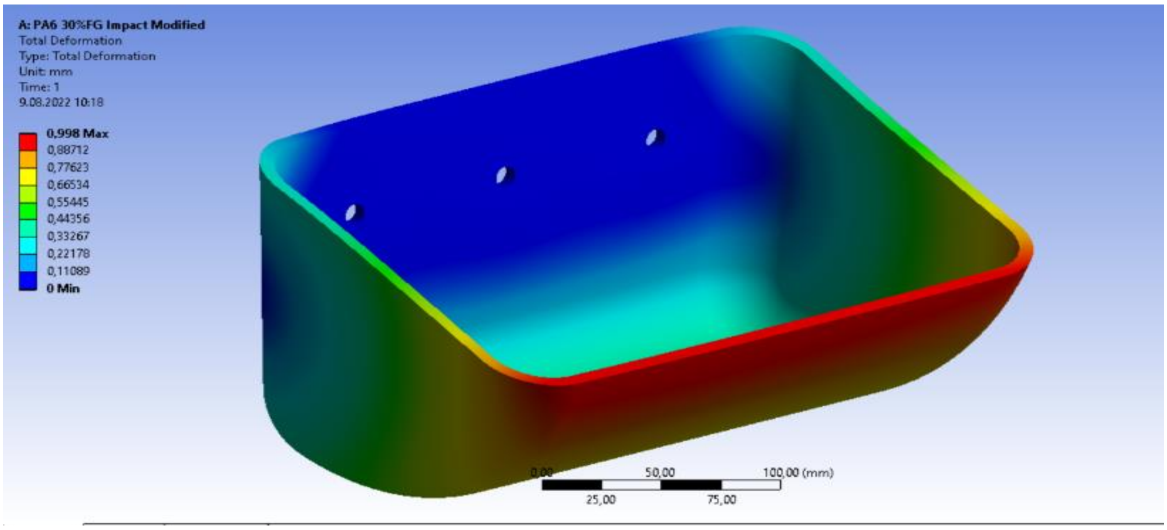
(a) HDPE (b) PA6 30% Fiberglass Impact Modified (c) PA6 30%-35% Fiberglass

3.2.2. Total Deformation

In structural FEA analyses in ANSYS® Mechanical, deformation results are important to understand the effects of stresses on material. ANSYS® provides a very useful deformation tool showing the results clearly. In this bucket, total deformation is 4.8184 mm when HDPE material is selected to be applied. It shows how much the bucket is deformed after loaded with grain. On the other hand, the results of PA6 with 30% Fiberglass-Impact modified and PA6 with 30%-35% Fiberglass was 0.998 mm and 0.922 mm respectively.



(a)



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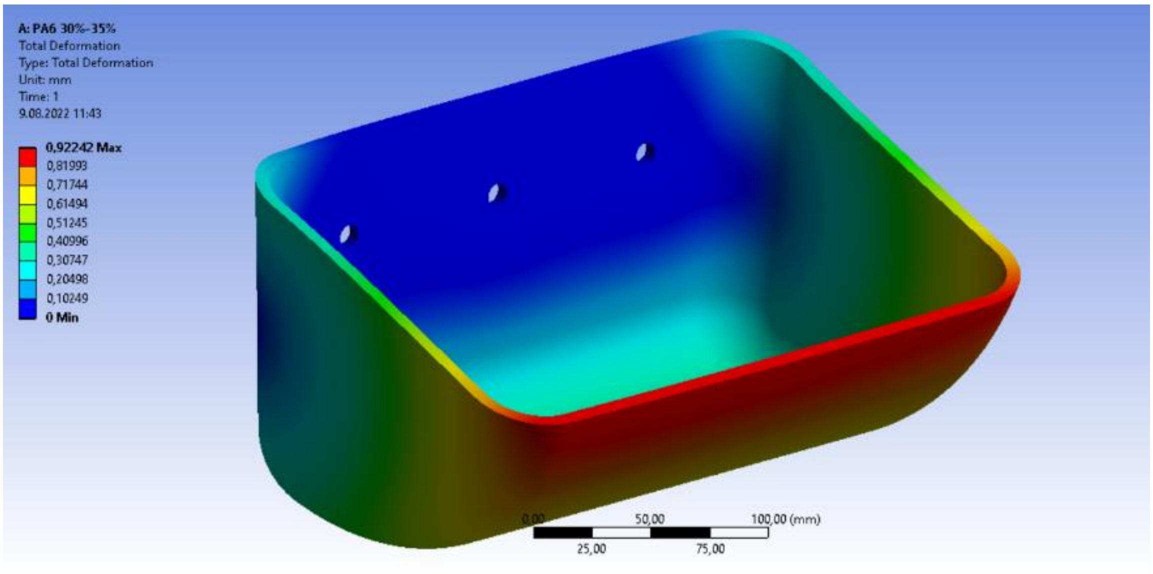


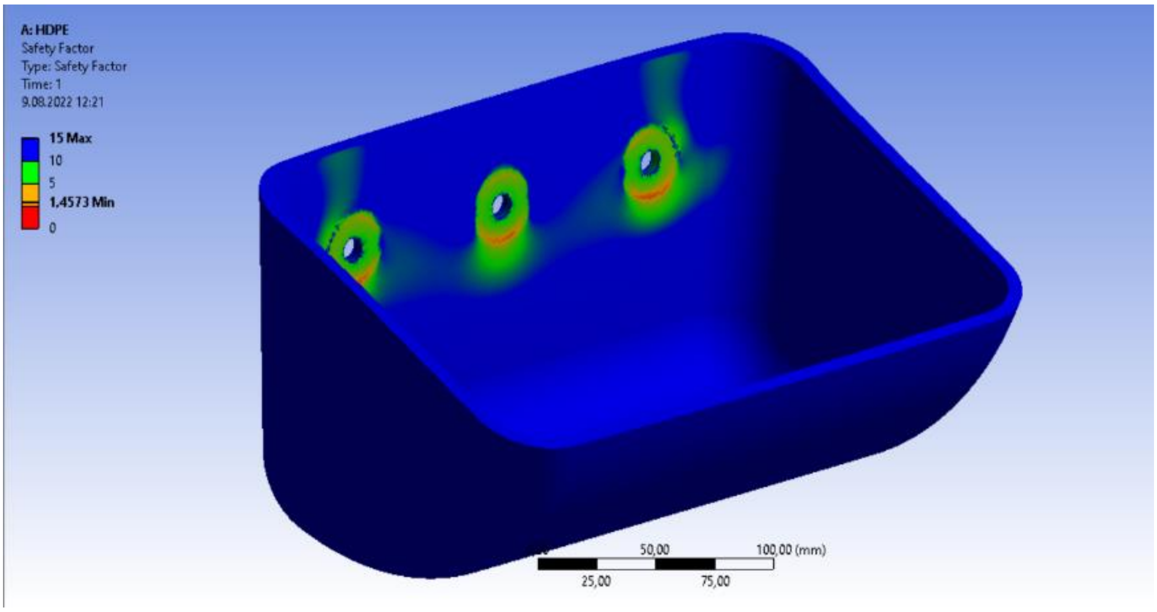
(c)

Figrure 3.3. Total deformation

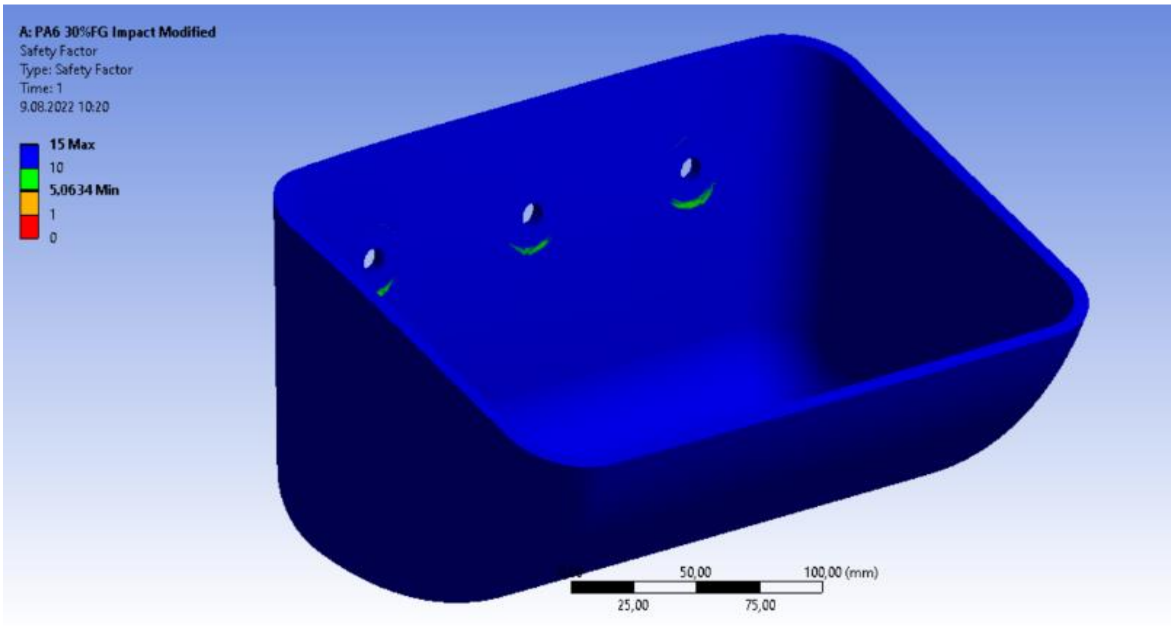
(a)HDPE (b) PA6 30% Fiberglass-Impact Modified (c) PA6 30%-35% Fiberglass

3.2.3. Safety Factor

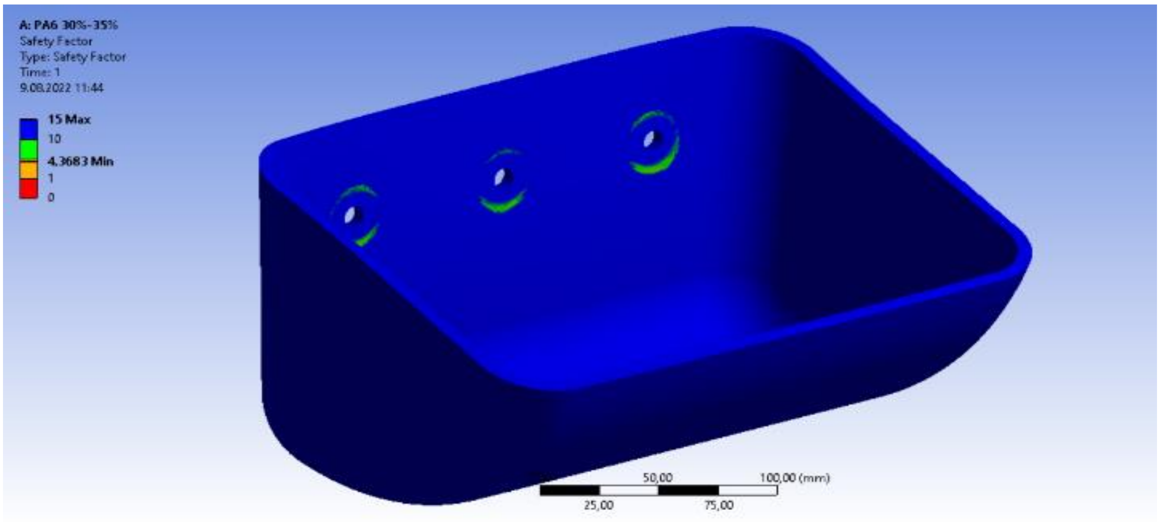
The safety factor is a typical way to represent a ratio between a measure of the maximum load that will not cause the specified type of failure and a matching measure of the maximum load that will be applied. It can also be represented as the ratio of the expected design life to the actual service life in some circumstances (Clausen et al., 2006). For the bucket, which was produced with HDPE, the safety factor was taken as 1.46 against the stress applied to it. On the other hand, it was 5.063 and 4.368 for PA6 30% Fiberglass-impact modified and PA6 30%-35% Fiberglass respectively.



(a)



(b)



(c)

Figure 3.4. Safety factor values

(a) HDPE (b) PA6 30% Fiberglass-Impact Modified (c) PA6 30%-35% Fiberglass

3.3. Fracture Toughness Value

Maximum equivalent von Mises stress was 15.635 MPa as seen in the Figure 3.2. (a) when HDPE material was used to produce bucket. With respect to the results of von Mises stresses seen in Figure 3.2.b. and Figure 3.2.c. fracture toughness values found out for the materials, PA6 30% Fiberglass-Impact Modified and PA6 30%-35%-Fiberglass with orders by using equations in section 2.4. With respect to these stresses, fracture toughness values were found in the case of traverse crack was taken as 2 mm in each side of the bolt hole.

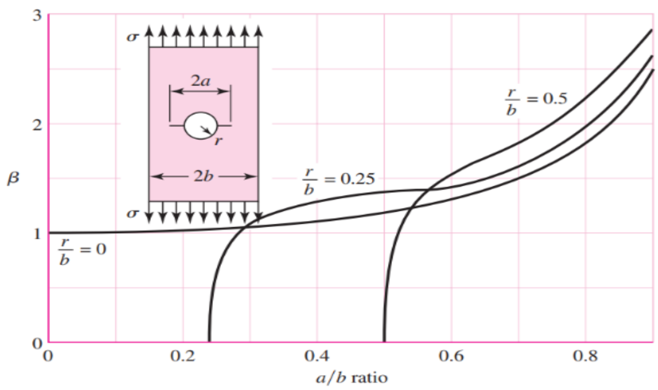


Figure 3.8 Tension in shape containing a circular hole with two cracks. (Budynas and Nisbett, 2011)

Depending on Figure 3.8 Tension in shape containing a circular hole with two cracks, (a) will be 7 mm and β is equal to 1.06 approximately.

For HDPE, PA6 with 30% Fiberglass-Impact modified and PA6 with 30%-35% Fiberglass materials by using the equation (7) and (8) the fracture toughness values are calculated. The results are shown in Table 3.2.

Table 3.2. Fracture toughness values of the candidate materials

Material/Fracture Toughness	K_I (MPa$\sqrt{m}$)	K_{IC} (MPa$\sqrt{m}$)
HDPE	2.45	3.68
PA6 with 30% Fiberglass-Impact modified	3.08	4.62
PA6 with 30%-35% Fiberglass	4.469	6.70

With respect to the results, it can be clearly concluded that the fracture toughness value for HDPE material with 2 mm cracks at each side of holes to fix the bucket to the belt with bolts was not enough even without taking a safety factor. On the other hand, the fracture toughness value of PA6 material with 30% Fiberglass-Impact Modified was enough to handle with that flaw occurred at sides of holes with safety factor of 1.5. Fracture toughness value for PA6 with 30%-35% Fiberglass was 4.469 MPa$\sqrt{m}$ without safety factor but when safety factor of 1.5 is taken the value is 6.70 MPa$\sqrt{m}$. From section 3.3 the allowed transverse crack length was taken as 2 mm as maximum from the information taken from Çukurova Silo with respect to the usage and maintenance conditions for the buckets. By applying the force as considering that the grain was wheat to be carried, HDPE material was analyzed by using ANSYS® Mechanical. Results showed that the HDPE material with current design had enough strength to carry grains without any failure in static loading conditions. However, with a transverse crack occurred at the edges of the bolt hole with 2 mm flaw, it was important to have superior fracture toughness value as current design and material used to produce buckets doesn't meet the requirement. With respect to the fracture toughness calculations for materials to be ranked, after safety factor of 1.5 was applied the optimum material is PA6 with 30% Fiberglass-Impact Modified.

PA6 has superior properties in long term usage when compared to HDPE, in addition to that has higher value of hardness and thanks to this property, it resists the damage, erosion and wear that material can come across in usage with respect to the contact of grain particles to the surface while deploying and loading conditions. So that, the maintenance cost would be lower compared to HDPE material. HDPE, PA6 material with 30%-35% Fiberglass and 30% Fiberglass impact modified were analyzed and the results were shown from Figure 3.1 to Figure 3.4 with order. Results showed that PA6 with both variations had superior mechanical properties when compared with HDPE. With using same amount of material, HDPE was lighter. But when same strength was demanded, PA6 was lightweight and cheaper. PA6 was found to be superior when compared with HDPE not only in long term but also in short term usage. The fatigue strength was approximately four time higher as long-term aspect. When the short-term usage parameters compared in between PA6 and HDPE, maintenance, durability against wear resistance, erosion, weight/cost and fracture toughness were much better.

4. Conclusion

In this study, as an advanced material selection, Ashby method was used as it is efficient way to choose the materials without personal judgment and necessity of experience. The material for the buckets that are used in grain transportation was studied to find out the optimum material which meeting the constraints by applying advanced material selection with Ashby method using CES Edupack material selection program which is suitable for the application of this method. Candidate materials were investigated and compared further. Some of the materials were suitable to choose for the production of bucket that transports 80 ton/hour at a working condition of -50 °C. After candidate materials were applied to a specific bucket geometry some values were found by applying FEA via using Ansys Mechanical software. Results of Ansys Mechanical software showed the material behaviours, deformation, safety factor and von Misses stress values for the materials that have already been used in silo elevator buckets and the materials found by applying Ashby method via CES software. For the specific type of bucket, it was concluded that both of PA6 with 30%-35% Fiberglass and PA6 with 30% Fiberglass-Impact modified were superior to HDPE and optimum materials for buckets for specified conditions. In conclusion, PA6 with 30% Fiberglass-Impact Modified material was found to be the optimum one in terms of price-strength as it could meet the constraints and enough fracture toughness with the consideration of 1.5 safety factor value to carry grains at a temperature of -50 ºC for this specific type of bucket.

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Declaration of conflict of interest

The authors declare that they have no conflict of interest.

Author Contribution Statements

The authors declare that they have contributed equally to the article.

References

Adin H., Ergün RK., Adin MŞ. Computer aided numerical damage analysis of the axle shaft. European Mechanical Science 2022; 6(3): 201-206.

Adin MŞ., Adin H., Ergün RK. Finite element analysis of safety pin in snowplow equipment. European Journal of Technique (EJT) 2022; 12(1): 89-92.

Ansys. Lecture 7: Mesh quality and advanced topics. Ansys, Inc 2015.

Ashby MF. Materials selection in mechanical design. 1th ed. UK: Elsevier Ltd; 2011.

Ashby MF., Schodek D., Ferreira P. Nanomaterials, nanotechnologies and design. 1th ed. UK: Butterworth-Heinemann; 2009.

Budynas RG., Nisbett JK. Shigley's mechanical engineering design. 9th ed. NY: McGraw Hill; 2011.

www.grantadesign.com (Access Date:21.07.2022)

Clausen J., Hansson SO., Nilsson F. Generalizing the safety factor approach. Reliability Engineering& System Safety 2006; 91(8): 964-973.

Cook RD., Malkus DS., Plesha ME., Witt RJ. Concepts and applications of finite element analysis. 4th ed., Wiley, New York, 2002.

Delibaş H., Uzay Ç., Geren N. Advanced material selection technique for high strength and lightweight spur gear design. European Mechanical Science 2017; 1(4): 133-140.

Dieter GE., Schmidt LC. Engineering design. 4th ed. Boston: McGraw-Hill Higher Education; 2009.

Koster K. Bulk material discharge of bucket elevators, especially high-capacity bucket elevators. Aufbereitungs-Technik 1984; 25(8): 450–463.

Qiang B., Yong B. Subsea pipeline design, analysis, and installation. USA: Gulf Professional Publishing 2014; 2014.

Patel S., Patel S., Patel J. A Review on design and analysis of bucket elevator. International Journal of Engineering Research and Applications (IJERA) 2012; 2(5): 018-022.

Patel TM., Bhatt MG., Patel HK. Analysis and validation of Eicher 11.10 chassis frame using Ansys. International Journal of Emerging Trends & Technology in Computer Science 2013; 2(2): 85-88.

Rademacher F. Non-spill discharge characteristics of bucket elevators. Powder Technology 1979; 22(2): 215–241.

Srikar VT., Spearing VT. Materials selection in micromechanical design: an application of the Ashby approach. Journal of Microelectromechanical Systems 2003; 12(1): 3-10.

Vaidya A., Pathak K. Mechanical stability of dental materials. Applications of Nanocomposite Materials in Dentistry 2019; 285-305.