Method Development for Sustainable Product and Service Design Strategy: Polymer Products with Shell Structures

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Graphical/Tabular Abstract (Grafik Özet)

Mechanical strength relationships were investigated through the analysis results by applying different mechanical connection points and different forces to the monophase and three-phase electric meters with two different geometric ratios. / İki farklı geometrik orana sahip monofaz ve trifaz elektrik sayacına farklı mekanik bağlantı noktaları ve farklı kuvvetler uygulanarak analiz sonuçları üzerinden mekanik dayanım ilişkileri araştırılmıştır.
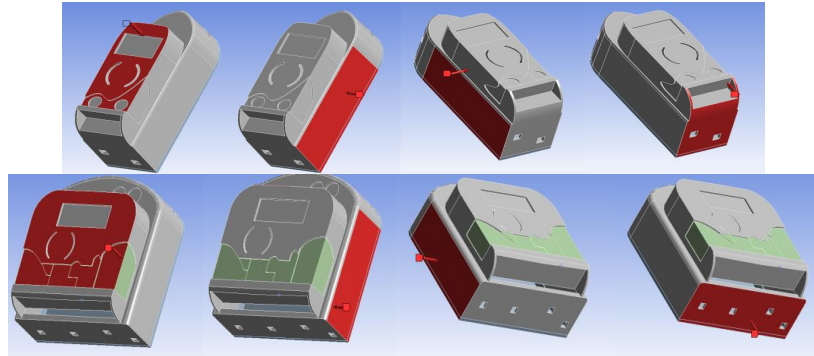

***Figure A**: Exerted forces for monophase and three-phase electricity meters / **Şekil A:** Monofaz ve trifaz elektrik sayaçları için uygulanan kuvvetler*

Highlights (Önemli noktalar)

➢ *CAD models are created in STEP format for products with different geometries. / Farklı geometrideki ürünlere STEP formatında CAD modeli oluşturulmuştur.*

➢ *Four different connection points were applied to the product in two different geometries to prove the hypothesis in every aspect. / Hipotezi her yönüyle kanıtlayacak iki farklı geometride ürüne dörder farklı bağlantı noktası uygulanmıştır.*

➢ *Stress, strain and strain analysis for each options were performed through the ANSYS software. / Her seçeneğe ait gerilim, gerinim ve şekil değiştirme analizleri ANSYS programı üzerinden yapılmıştır.*

Aim (Amaç): *It is aimed at developing a sustainable design method to minimize time and resource losses arising from incompatibilities in industrial design and engineering design processes. / Endüstriyel tasarım ve mühendislik tasarımı süreçlerindeki uyumsuzluklardan yola çıkılarak oluşan zaman ve kaynak kayıplarının minimize edilmesi için bir sürdürülebilir tasarım yöntemi geliştirilmesi amaçlanmıştır.*

Originality (Özgünlük): *Sustainable design method based on mechanical strength was developed. / Mekanik dayanımdan yola çıkılan sürdürülebilir tasarım yöntemi geliştirilmiştir.*

Results (Bulgular): *Considering the geometric ratio difference in the three axes, it has been observed that each polymer part has its own unique connection point to show higher strength. / Üç eksende geometrik oran farkı da göz önünde bulundurularak her polimer parçanın daha yüksek mukavemet göstermesi için kendine özgü birleşme noktası olduğu görülmüştür.*

Conclusion (Sonuç): *It has been observed that if the mechanical connection points are made correctly in polymer products, the mechanical strength will increase. With this method, which will contribute to the sustainable design literature, carbon emissions in service processes will be directly affected due to resource consumption. / Polimer ürünlerde mekanik bağlantı noktalarının doğru yapılması durumunda mekanik dayanımın artacağı görülmüştür. Sürdürülebilir tasarım literatürüne katkı yapacak bu yöntem ile hizmet süreçlerindeki karbon emisyonu kaynak tüketiminden ötürü doğrudan etkilenecektir.*

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Abstract

Sustainability in industrial design aims to provide a better world for future generations by reducing the energy and resource consumption used in the design of products or services. After the industrial design is completed, the products are transformed into a form that will take their place in our lives through the engineering design process. However, during this process, the features that industrial design focuses on may be lost or damaged. This situation reveals the importance of sustainable design strategies by creating various economic and time losses. In order to minimize the aforementioned problems, changes were made to the mechanical design of the products whose industrial design was carried out by an engineering company. It is aimed to strengthen the mechanical strength of the form with changes that do not affect the outer form. Four options were created for each of the two electricity meter models, the structures of which are shell structures and the products to be produced with polymer materials, which differ in size and three-axis ratios, and mechanical strength was analyzed with engineering analysis programs. With the method in the study, it has been revealed that the problem can be solved without the need to make radical changes due to strength in the industrial designs of product groups with similar structures. Thus, a method has been developed within the framework of sustainable product and service design strategies, and it is thought that this method will increase efficiency in the business model and cause less energy and resource consumption.

Sürdürülebilir Ürün ve Hizmet Tasarımı Stratejisi için Yöntem Geliştirme: Kabuk Strüktüre Sahip Polimer Ürünler

Öz

Endüstriyel tasarımda sürdürülebilirlik, ürünlerin veya hizmetlerin tasarlanması sürecinde kullanılan enerjinin ve kaynakların azaltılarak verimli kullanılması ile gelecek nesillere daha iyi bir dünya bırakmayı içermektedir. Ürünler, endüstriyel tasarım gerçekleştirildikten sonra mühendislik tasarımı süreci ile birlikte hayatımızdaki yerlerini alacak forma dönüştürülmektedir. Ancak bu süreç zarfında endüstriyel tasarımın odaklandığı özellikler yitirilebilmekte veya zarar görebilmektedir. Bu durum çeşitli ekonomik ve zaman kayıplarını oluşturarak sürdürülebilir tasarım stratejilerinin önemini ortaya çıkarmaktadır. Söz konusu problemlerin en aza indirgenebilmesi için özel bir mühendislik şirketi ile endüstriyel tasarımı gerçekleştirilen ürünler üzerinden mekanik tasarımda değişikler yapılmıştır. Dış forma etki etmeyen değişiklikler ile formun mekanik mukavemetinin güçlendirilmesi amaçlanmıştır. Strüktürleri kabuk strüktür olan, polimer malzeme ile üretilecek ürünlerin ölçü ve üç eksene göre oranlarının farklı olduğu iki elektrik sayacı modeli üzerinden dörder opsiyon oluşturulmuş, mühendislik analizi programları ile mekanik mukavemet analiz edilmiştir. Çalışmadaki yöntem ile benzer strüktüre sahip ürün gruplarının endüstriyel tasarımlarında mukavemet sebepli köklü değişikliklere gidilmesine gerek olmadan da sorunun çözülebileceği ortaya konmuştur. Böylece sürdürülebilir ürün ve hizmet tasarımı stratejileri çerçevesinde bir yöntem geliştirilmiş, söz konusu yöntem ile iş modelinde verimin arttırılarak daha az enerji ve kaynak tüketilmesine sebep olması düşünülmektedir.

1. INTRODUCTION (GİRİŞ)

Within the framework of industrial design, the concept of sustainable design has been developed with many design strategies, and these design strategies are directly related to providing a better world/environment that will not harm future generations [1]. Because the environmental and social activities experienced in the 1970s and 1980s revealed how important the concept of sustainability is. According to these sentences, the basic philosophy of the concept of sustainability is to provide a sustainable world for future generations. Industrial design is one of the product development processes that can directly affect many steps, such as product design, material selection and conformity to production methods, designs that create efficient resource use and service efficiency within the framework of the product life cycle, modular features, and packaging design of the product [2,3]. However, it should not be forgotten that in many design works, the industrial designers fulfill the material and production method within the constraints given to them. Creating the concept of sustainability with these constraints is directly dependent on the industrial plant where the work is done. If industrial designers follow a sustainable product and service design strategy, the product they will design will have more impact on the business model [4]. This situation is explained by steps such as the product being designed, reducing the product variety in the market by eliminating many products (using variety), reducing the waste in the service phase by turning to digital drawings instead of paper and similar drawing tools or increasing efficiency directly in the service phase [5]. In this article, it is aimed to increase efficiency in the business model within the framework of sustainable product and service design and to reduce the resources to be spent on the creation of the service.

An industrial product is a product produced by industrial production techniques. Industrial design designs the relationship between the consumer and the producer of such products [6]. One of the most important limitations in the design of industrial products is structure. Structures are a structural feature that generally determines the mechanical properties, production methods, and form properties of the product. These structural features are generally examined in 8 types in the industrial design discipline. These are; shell structures, solid structures, frames, membranes, plates, cages, tensile structures, and mixed structures [7]. Many of the products seen in daily life consist of shell structures. The reason for this situation is the easy formability

in shell structure applications, especially in the design of the polymer material, and good results that can be obtained in production. In addition, it is a very suitable structure type economically [8,9].

Polymers are the name given to the more complex material that is formed by the combination of monomer molecules formed by organic or inorganic elements under a certain force. The structure formed by the combination of "n" monomers is called a polymer. When polymers are classified according to their internal structures, they are divided into three: thermoplastics, thermosets, and elastomers. While thermoplastics are polymers that can be formed with heat, such materials can be formed by reheating. Thermosets are materials that become rigid when formed by heat. Re-cycling is very problematic at today's level of technological development and it's an area where R&D studies continue for thermosets. Elastomers are materials that include both elastic and viscosity properties. They are heavily strengthened against plastic deformation [10,11]. The most common example in today's world is rubber. Materials called polymers in today's industry are often thermoplastics. ABS, the material whose chemical name is Acrylonitrile Butadiene Styrene, is one of the most common thermoplastics. When heat is transferred during production and the mechanical (density: 1,000-1,200 kg/m3, tensile strength: 28-55 MPa) and thermal performance of the product (resistivity: 3.3 x1021 - 30 x1021 µohm.cm, specific heat: 1,400-1,900 J/kg.oC, t-conductivity: 0.19-0.34 W/m/k) that will emerge after it can be formed in this process [12]. According to those specifications, it can be said that thermoplastics are mostly used polymers for shell structure because of lower heat resistance and easy formability. The characteristic features of the elements in the chemical structures of the polymers make it possible to create custom polymers by combining them with various chemical processes, and this shows that the polymer industry is still an area suitable for research and development. The variety and flexibility of products with different strengths result from each other, including the products of different companies that produce ABS material, which can also be found under the same name. If the designed part allows, one of the most suitable production methods for polymers is injection molding. When there is a restriction to use polymer materials in an industrial design project with a plastic injection molding method, one of the first structure types to be looked at is the shell structure. However, if the volume of the furnace in which the part will be produced is smaller than the part, choosing a shell structure can also create an economic disadvantage with its production method

[13]. Therefore, the choice of structure is a very important design step. In order to use minimum energy and get maximum efficiency in the glass transition process, polymers are expected to reach a certain viscosity by heating. The viscosity values should also be chosen in serious relationship with the production method of the polymers [14]. With this viscosity, the temperature is reduced while the mold is fully filled, the product solidifies and becomes a ready-made product with the expected mechanical and thermal properties. In general terms, lower viscosity means a higher flow rate for filling the shell.

Industrial products with shell structure, which is the focus of the study, are monophase and three-phase electricity meters. The studies were created as a result of mutual data exchange with the R&D department of an engineering company. Academically, it is planned that the data will benefit those who will conduct new studies in this sector, and it is aimed to contribute to the sustainable product and service design literature globally as new methods for increasing the mechanical strength in product designs. In order to fulfill these goals, detailed 3-dimensional analysis of monophase and three-phase electricity meters formed from the shell structure have been made and studies have been created on how to increase the mechanical strength without changing the outer form. Steps are taken to increase mechanical strength; It was thought that the changes to be made due to their size, wall thickness, and morphological differences should be different for monophase and three-phase electricity meters.

In the literature, it is seen that various studies within the scope of engineering design improvements are made due to both sustainability and economic advantages [15,16]. However, with this study, it has been shown that a joint improvement is possible without damaging each other's industrial design and engineering design processes. This is a step that will make the process more sustainable within the framework of the sustainable product and service design strategy. Technically, it is known that the products will consist of two parts as male and female parts, it is thought that the joint points can be used to support the general structural strength [17]. However, according to the hypothesis established due to the differences in the surface area on which the forces will be applied, it has been thought that the monophase and three-phase products will have different joint points. In the case of a mismatch between the thoughts and analysis results, analysis

types were increased up to four options, and optimum results were searched.

As a result of the analysis made according to the hypothesis, it was seen that separate steps should be taken for monophase and three-phase. The joint points of the products have been determined for male and female parts, and the thickness and area sizes of the contact surface areas of the parts are specified. The hypothesis of the study constitutes a universal result, a study that can be applied by businesses and academic people with the application of the desired steps in polymer products with shell structure and obtaining positive results has been revealed. Since it has been proven that more efficient results can be obtained with the use of less resources in terms of sustainable product and service design, it has been understood that the concepts of a green world and a green future can be supported by such sustainability activities (to the stages of the formation of the service) in the presence of rational data.

2. MATERIALS AND METHODS (MATERYAL VE METOD)

In order to make the analysis in the study, the product designs were designed with computer-aided design (CAD), which is numerical-based design software [18,19]. Along with the design of the models, the desired analyzes were applied through the Ansys software. Since the numerical operations are performed for each mesh on the model in computer analysis, it is much more effective and efficient than on-paper operations. In this context, it can be said that the study is directly related to industrial design and engineering design processes (computer-aided design and computer-aided manufacturing) [20].

In the definitions made for the analysis software, the material is selected as ABS. The use of this material is widely available in the global market due to its easy formability and decent mechanical performance values. The fact that it is a petrochemical product also raises questions about the sustainability of the product [21]. The requirement to mix new raw materials at each recycling stage, due to their mechanical and thermal properties that weaken with each recycling stage, also shows the weakness of sustainability in recycled materials. Since there are mechanical and thermal performance problems in thermoplastics produced directly from natural materials such as

sugar, their use remains very limited, and generally, it is not possible to proceed from model-making to

the next stage (prototype stage). Therefore, it is foreseen that the technological development in

material technologies will continue. And it is focused on decreasing resource consumption in services and operations for sustainable movements.
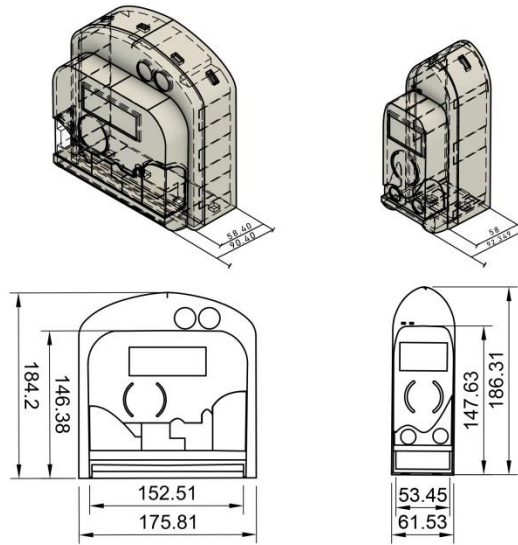

Figure 1. General dimensions of three-phase and monophase electricity meter products, wall thickness 3 mm (Trifaz ve monofaz elektrik sayacı ürünlerine ait genel ölçüler, et kalınlığı 3 mm)

The designed products' visuals and dimensions are given in Figure 1. At this point, studies were created on the general characteristics of the given product. The main male and female joint parts of the products will be created by the calculation of the center of gravity, so the center of gravity formula has been used for this operation.

Center of gravity calculations for the functional geometry in accordance to mass distribution [22],

$$m = rho. V$$

m: mass of the object, rho: density, V: volume of the object

$$cg . W = g . \iiint i . rho(x,y,z) \, dx \, dy \, dz$$

cg: center of gravity, W: total weight of the object, g: gravitational constant, i: distance for reference line

Stress and strain analyses were performed because numerically based strength analyses were required to understand the accuracy of the hypothesis. According to the theoretical background of this subject, strain is a measure of the body's distortion, while stress is related to the strength of the material from which it is built. Because many of the formulas and design rules stated in engineering codes are based on engineering principles, a solid understanding of the fundamentals of this subject is critical for the design of any machine or structure [23].

Surface loads and body force can both be applied to a body. Concentrated forces are surface loads that act on a small area of contact, whereas distributed loadings act over a broader surface area of the body. A body force is developed when one body exerts force on another's body without direct physical contact between the bodies.

A body's equilibrium requires a balance of forces to prevent it from translating or accelerating along a straight or curved path, as well as a balance of moments to keep it from rotating. The equations of equilibrium are used to express these circumstances mathematically:

$$\sum F = 0 \qquad (1)$$

$$\sum M_o = 0 \qquad (2)$$

The sum of all forces operating on the body is represented by F, and the sum of the moments of all forces acting on any point O on or off the body is represented by Mo.

$$\sum F_x = 0 \qquad \sum F_y = 0 \qquad \sum F_z = 0 \qquad (3)$$

$$\sum M_x = 0 \qquad \sum M_y = 0 \qquad \sum M_z = 0 \quad (4)$$

$$\epsilon = \frac{\Delta l}{L} \qquad (6)$$

Stress is defined as force per unit area within materials that arise from externally applied forces, uneven heating, or permanent deformation and that permits an accurate description and prediction of elastic, plastic, and fluid behavior.

$$\sigma = \frac{F}{A} \ (N/M^2) \qquad (5)$$

F: Force (N), A: Area (m²)

Applied stress can be of two types: these are tensile stress and compressive stress. Tensile stress is the force applied per unit area, increasing a body's length (or area). Objects under tensile stress becomes thinner and longer. Compressive stress is the force applied per unit area, which decreases the length (or area) of a body. The object under compressive stress becomes thicker and shorter.

Strain is the amount of deformation experienced by the body in the direction of force applied, divided by the initial dimensions of the body. Expressed as elongation and original length, that makes it a unitless property.

Strain: ϵ, Change in Length: Δl (m), Original Length: L (m)

Strain can be of two types: these are tensile strain and compressive strain. Tensile strain is the change in the length (or area) of a body due to the application of tensile stress. Compressive Strain is the change in the length (or area) of a body due to the application of compressive strain.

About the Stress-Strain Curve, once the stress and strain data from the test are known, then the results can be plotted to produce a curve called the stress–strain diagram. This diagram is very useful since it applies to a specimen of material made of any size. To obtain a stress-strain diagram, eq. (5) & (6) are given on the -x and -y axis. In addition to these equations, stress can be observed via Hooke's law.

$$\sigma = E \, \epsilon \qquad (7)$$

E: Modulus of Elasticity / Young's Modulus (GPa)

The Stress & Strain diagram varies due to the material type such as ductile and brittle materials. Any material that can be subjected to large strains before it fractures is called a ductile material. Materials that exhibit little or no yielding before failure are referred to as brittle materials.
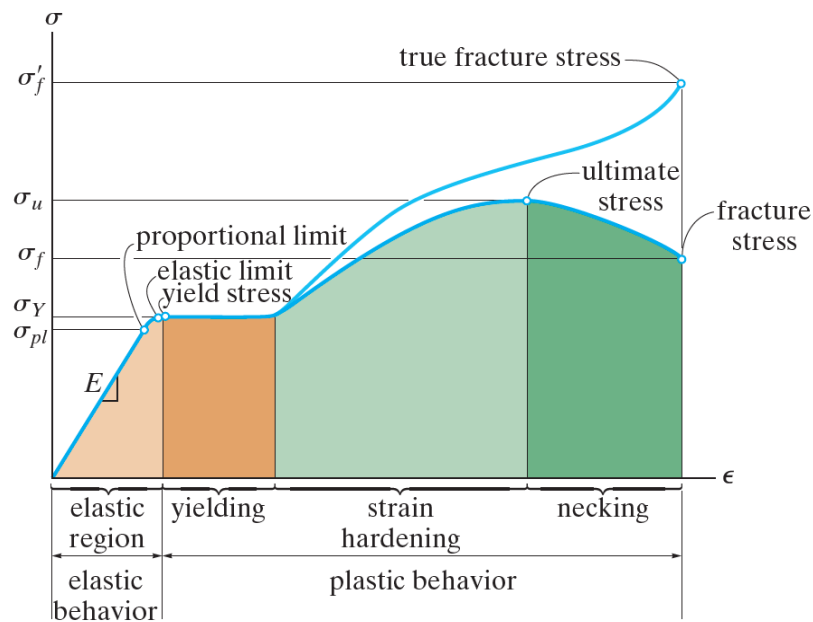

Figure 2. Conventional and true stress–strain diagram for ductile material (Sünek malzemeler için geleneksel ve gerçek gerilim-gerinim diyagramı) [23]
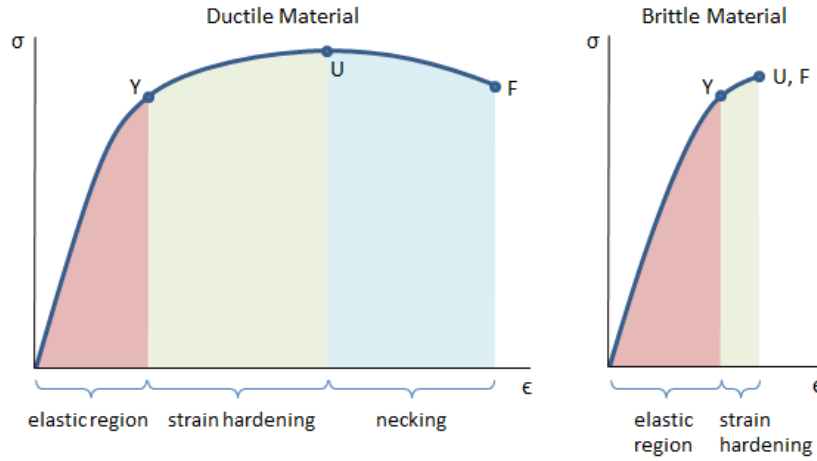
Figure 3. Comparison between ductile and brittle Stress & Strain diagram (Sünek ve kırılgan malzemeler için gerilme-gerinim diyagramının karşılaştırılması) [24]

Analysis background for existing study; the study validation proceeded by examining its total deflection, total stress, and total strain analysis. To have an accurate and meaningful result, Von Mises's total stress & strain analyses are referred. Studies are held via Ansys V22.1.

Before proceeding to analysis results, Von-Mises expressions are given. In the light of theoretical and numerical analysis, the best-resulting electricity meter design will be determined and the study will be completed by finding the true steps to increase mechanical strength without changing the outer form.

Analyses background for existing study; while designing a product, Von Mises stress to be a safe haven. An engineer can use this information to say that his design will fail if the highest value of Von-Mises stress created in the material is greater than the material's strength. In most circumstances, it works well, especially when the material is ductile. One of the easiest ways to check when a material fails is a simple tension test. Here the material is pulled from both ends. When the material reaches the yield point (for ductile material) the material can be considered as failed. The simple tension test is a unidirectional test. A simple tension test is represented in Figure 2. In addition, the ductile and brittle materials' transition graphs are shown in Figure 3.
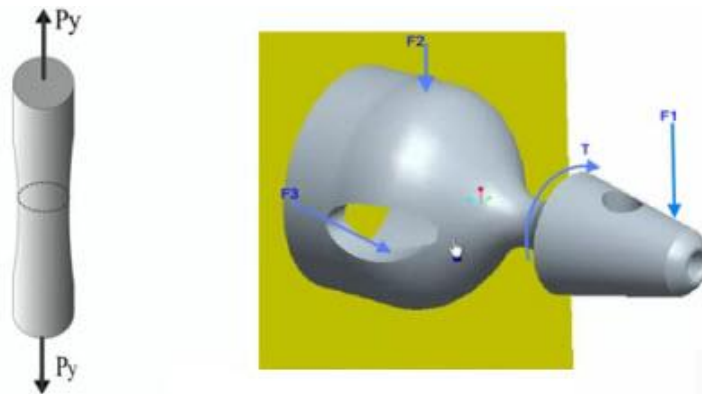

Figure 4. A simple tension test and a real-life loading condition (Basit bir gerilme testi ve gerçek hayat yükleme koşulu) [25]

Now consider the situation in the second part of Figure 2; an actual engineering problem with a complex loading condition. In such complex situations, different approaches are needed. To examine such complexities, a failure theory called 'normal stress theory' is used. Many years of engineering experience has shown that normal stress theory doesn't work in most cases. The most preferred failure theory used in industry is 'Von-Mises stress'. The distortion energy failure theory gives rise to the concept of Von Mises stress. The failure theory of distortion energy compares two types of energies: the first is distortion energy in the real world and the second is distortion energy

in theory. At the point of failure, distortion energy in a basic tension situation. Failure happens when the distortion energy in the current case is greater than the distortion energy in a simple tension scenario at the point of failure, according to this idea. A simple tension test visual is given in Figure 4.

Distortion energy required per unit volume, ud for a general 3-dimensional case is given in terms of principal stress values as:

$$u_d = \frac{1+v}{3E}\left[\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}{2}\right] \quad (8)$$

$$u_{d,sim} = \frac{1+v}{3E}\sigma_y^2 \quad (9)$$

If eq. (8) and (9) are combined and energy failure theory is written;

$$\left[\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}{2}\right]^{1/2} \geq \sigma_y \quad (10)$$

$$\left[\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}{2}\right]^{1/2} = \sigma_v \quad (11)$$

So, failure criterion becomes;

$$\sigma_y \geq \sigma_v \quad (12)$$

3. RESULTS OF ANALYSES AND DISCUSSION (ANALİZ SONUÇLARI VE TARTIŞMA)

As indicated in the study, various processes were applied in order to increase the mechanical strength of the product without changing the outer form. According to this, the first step was created to fit the male and female parts together from the center of gravity. By extending the length of the male part until it encounters any obstacle in the inner part, it was expected to determine the optimum value, and analyses were created accordingly. The minimum male part length was accepted as 4 mm, which is the thickness value of the product in that region, and continued. With this step, the part is prevented from becoming weaker than necessary. Moreover, the maximum value of the inner length is determined as 10 mm for the male part. The reason for this situation is that the part starts to contact with other parts. These processes showed that a value between 4 and 10 mm male part length is optimum. However, this process is an approach based on a gravity-centered splitting point.
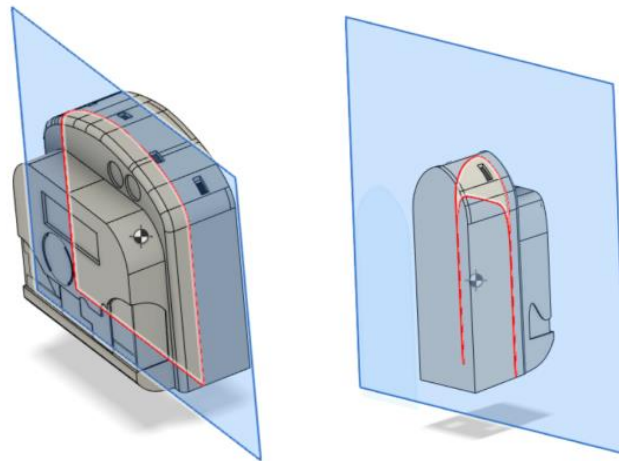

Figure 5. Center of gravity for three-phase and monophase electricity meters (Trifaz ve monofaz elektrik sayaçları için ağırlık merkezleri)

In the second hypothesis, the plate on the point where the product is fixed is cut to become a joining point for the male and female parts. According to this situation, the internal mechanical parts are positioned on the base plate to prevent the product from disintegrating against lateral forces. The products' visuals are given in Figure 5, showing the center of gravity from CAD. Between the lengths of

4 and 10 mm, the optimum length of the male part was considered as a constraint. It was determined according to the hypothesis that the optimum joining points should be different due to the surface areas, product weights, differences in the center of gravity, and different ratios of the products on the three axes. Accordingly, the results of the analyses also matched the hypothesis.
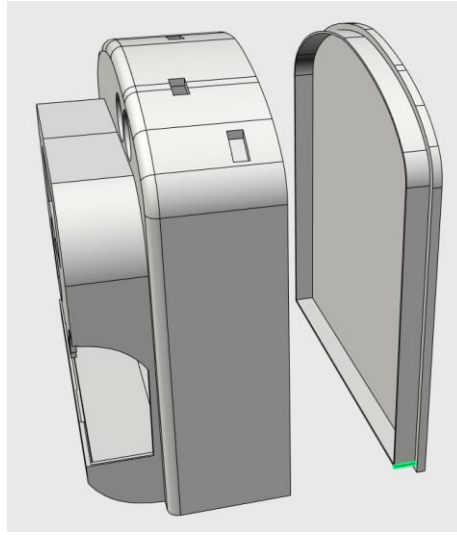
Figure 6. Splitting three-phase electricity meter from lower portion, length of male part shown as green line (Trifaz elektrik sayacının arka bağlantı yüzey noktasından ayrılması, erkek parça uzunluğu yeşil çizgi ile gösterilmektedir)

To examine the suitable design, 4 studies were held for both three-phase and monophase electricity meter products according to deformation, stress, and strain analyses. These studies are compared with respect to Total Deformation, Von Mises Stress & Von Mises Strain Analyses. These 4 types of parts are;

For Monophase Electricity Meters:

• 10 mm Inner Contact at Lower Portion

• 4 mm Inner Contact at Lower Portion

• 4 mm Inner Contact at Center of Gravity

• 10 mm Inner Contact at Center of Gravity

For Three-phase Electricity Meters:

• 10 mm Inner Contact at Lower Portion

• 4 mm Inner Contact at Lower Portion

• 4 mm Inner Contact at Center of Gravity

• 10 mm Inner Contact at Center of Gravity

The lower portion is described as shown in Figure 6. To examine a suitable proposal, four surfaces for each electricity meters are expressed to a certain force, and one face is fixed. The figure below represents the faces and exerted force. This force is:

• 100N vertical compression on front surface

• 200N vertical compression on side surfaces

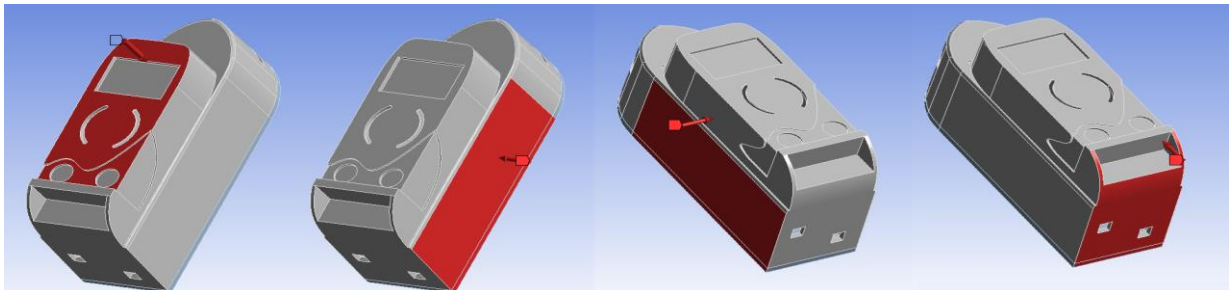• 500N vertical compression on bottom surface

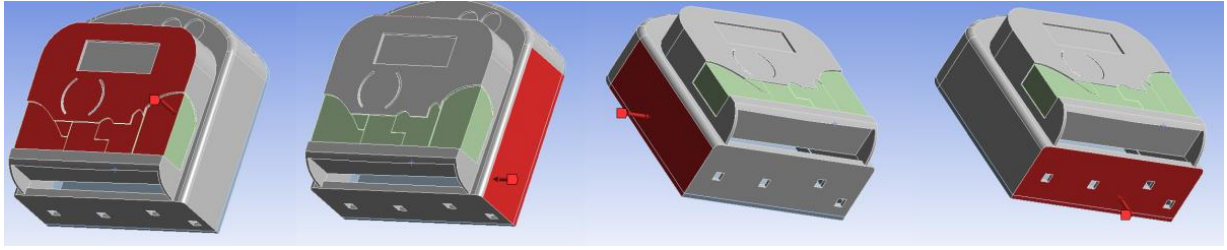**Figure 7.** Monophase exerted forces (Monofaza uygulanan kuvvetler)

Figure 8. Three-phase exerted forces (Trifaza uygulanan kuvvetler)

Figure 7 and Figure 8 represent the exerted forces of monophase and three-phase products. According to the analysis results; the total deformation, total stress, and total strain figures of the monophase electricity meter are given here. The same study analysis has been created for a three-phase electricity meter, too.
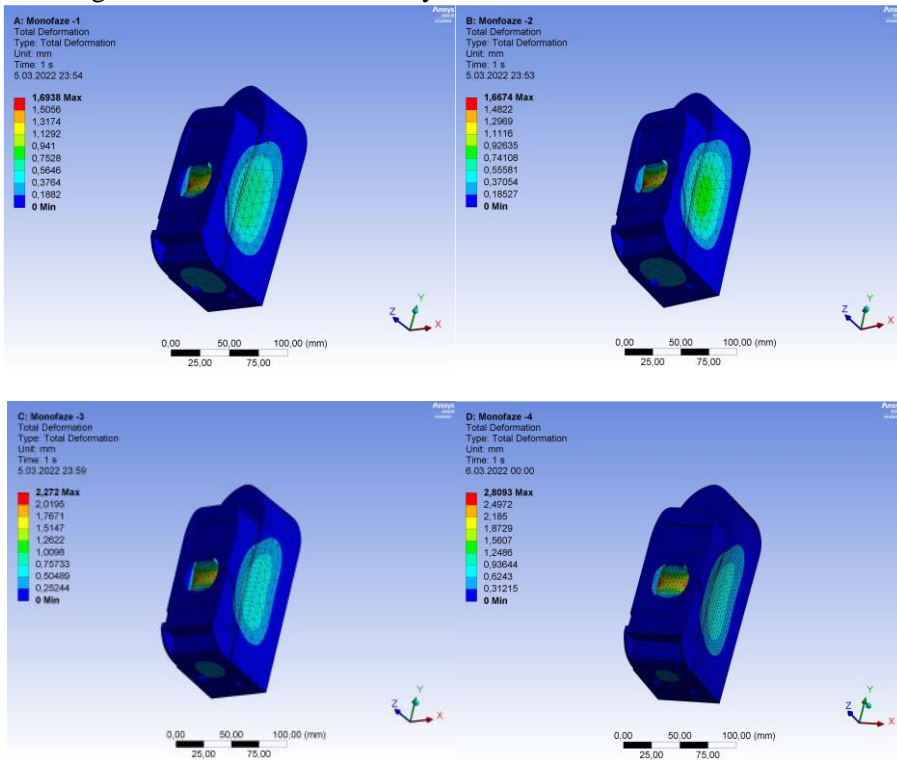

Figure 9. Total deformation analyses for monophase (Monofaz için toplam yer değiştirme analizi)
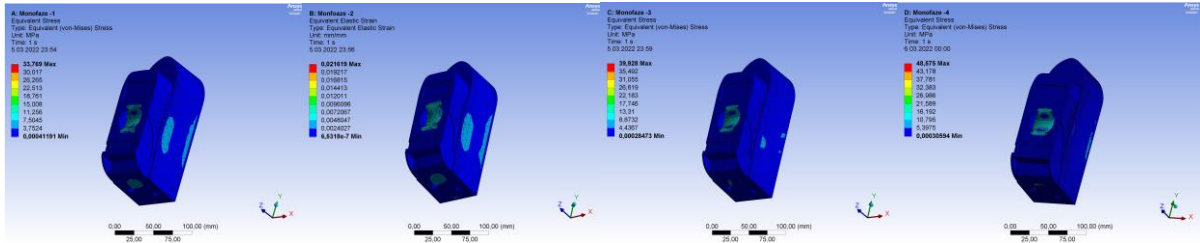

Figure 10. Total stress analyses for monophase (Monofaz için toplam stres analizleri)
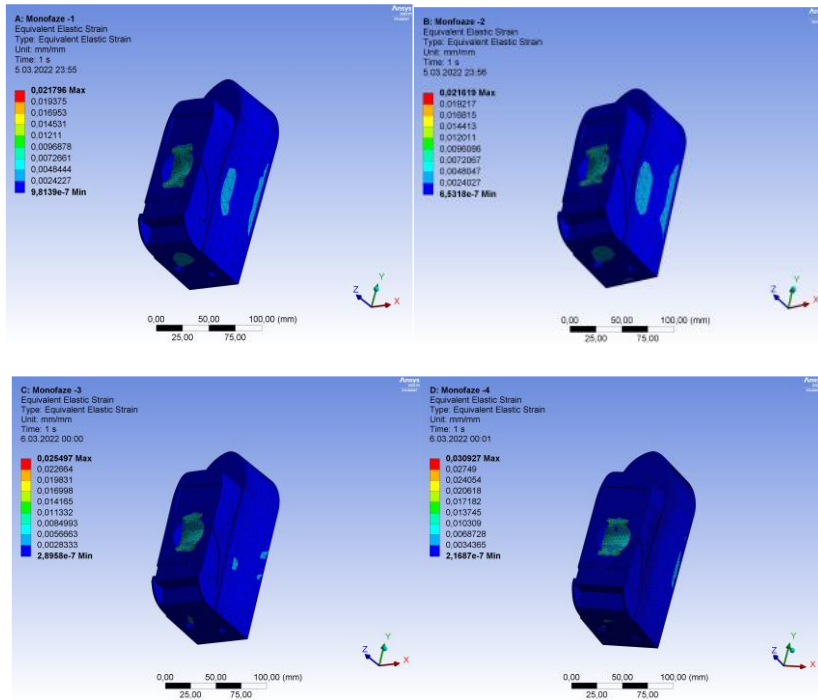
Figure 11. Total strain analyses for monophase (Monofaz için toplam gerinim analizi)

Total deformation analyses resulted as shown in Figure 9 for the monophase product. In addition, the visuals that belong to total stress for monophase are given in Figure 10. Total strain analyses were made according to four steps that are shown in Figure 11.

These three types of analyses are also made for three-phase product. Detailed analysis results are given in Table 1 and Table 2 for maximum values of total deformation, total stress, and total strain.

Table 1. Monophase Results as Maximum (Monofaz için maksimum sonuçlar)

Monophase Electric Meter	Monophase -1	Monophase -2	Monophase -3	Monophase -4
Total Deformation (mm)	1,6938	1,6674	2,272	2,8093
Total Stress (MPa)	33,796	33,487	39,928	48,575
Total Strain	0,021796	0,021619	0,025497	0,030927

Table 2. Three-phase Results as Maximum (Trifaz için maksimum sonuçlar)

Three-phase Electric Meter	Three-phase -1	Three-phase -2	Three-phase -3	Three-phase -4
Total Deformation (mm)	3,9737	4,4377	3,0481	3,1115
Total Stress (MPa)	25,615	28,047	19,444	20,814
Total Strain	0,0017678	0,019356	0,013853	0,01558

By referring to Table 1, it can be stated that a suitable design for the monophase electricity meter would be Monophase-2, which has 10 mm of contact surface in the lower portion. This statement is done by considering maximum analysis properties and picking the lowest data. Such a statement can be made by referring to Table 2 in terms of the three-phase electricity meter. Three-phase-3 would be the most suitable design that has a 4mm contact point at the center of gravity.

The difference between monophase and three-phase models is expected to occur due to geometry differences. Since the three-phase's overall geometry is larger than the monophase, exerted force showed its effects accordingly. So, having 2 different designs in the industry would be the most effective solution in terms of engineering aspects. If cost design singularity is taken into account, a suitable solution would be design-3 in terms of a common contact point idea. Since two different molding and tooling studies will take place for these 2 types of electricity meters, design 2 for monophase and design 3 for three-phase is expected to be the most overall effective solution.

4. CONCLUSIONS (SONUÇLAR)

According to the study, it has been seen that it is possible to increase the mechanical strength of products without interfering with the outer form during the engineering design processes. However, it has been observed that one of the most important factors to be considered in the application of the processes are the proportions of the parts in three axes. According to this ratio and the location of the center of gravity, including the weight to be carried by the product, suitable joining points should be determined. Business and individual designers who want to reduce energy and resource use by applying a sustainable product and service design strategy can use this study. For those who will apply to the study independently within the scope of business or academic studies, the steps that they should follow in their own studies according to the results of the study are:

• First of all, the industrial design of the product must include a shell structure and consist of thermoplastic material because of easy formability in the injection molding production method.

• Then the weights to be carried by the product should be determined. Accordingly, when an

actively working product is positioned, it should be determined where it will not be exposed to stress and impacts. For analysis, these regions should be defined as a fixed region and no stress should be applied.

In the first step, separation from the center of gravity should be performed in order to determine the points where the product will be combined as male and female parts and to determine the features that it will perform optimally. Optimum values should be searched by extending from the thickness data in the center of gravity of the product to the point where the extension of the male part will be prevented. In the second step, the floor, which is fixed in such a way that it is not smaller than the plate thickness value at the connection point of the product, should be separated from the body as a single plate. The maximum and minimum male part lengths determined in the first step should be accepted in this field, and optimum values should be searched with analyses. However, it should not be forgotten that the plane selection at the joint points of the female and male parts should be made parallel to the plane on which the product is fixed. Thus, a successful method has been established that will minimize the need for modifications to the outer form. This will directly reduce the consumption of energy and resources during the process of service.

DECLARATION OF ETHICAL STANDARDS (ETİK STANDARTLARIN BEYANI)

The author of this article declares that the materials and methods they use in their work do not require ethical committee approval and/or legal-specific permission.

Bu makalenin yazarı çalışmalarında kullandıkları materyal ve yöntemlerin etik kurul izni ve/veya yasal-özel bir izin gerektirmediğini beyan ederler.

AUTHORS' CONTRIBUTIONS (YAZARLARIN KATKILARI)

Mustafa CANBULAT: He designed the main products of article and he has researched on sustainable design strategies.

Ürün tasarımlarını gerçekleştirmiş ve sürdürülebilir tasarım stratejileri üzerine araştırmalar yapmıştır.

Habip Akın HACIMUSALAR: He analyzed numerical based stresses, strains and deformations of parts.

Parçaların gerilim, gerinim ve şekil değiştirmelerini sayısal tabanlı programlarda analiz etmiştir.

Mine POYRAZ: She has researched the main design literature and sustainable needs.

Konu kapsamındaki tasarım literatürü ve sürdürülebilir ihtiyaçlar üzerine araştırmalar yapmıştır.

CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

Bu çalışmada herhangi bir çıkar çatışması yoktur.

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