Research Article

Block Sponge Compression and Packaging System Design and Analysis with Finite Element Method

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Abstract

In today's sponge industry, sponges are large and take up space, so there is an excessive amount of shipments for delivery. For this reason, there is a need for a system that can pack the sponge in order to reduce the height of the sponge and to ensure the shipment of more products at once, in order to compress the sponge and prevent it from returning to its original state. In this study, the design and analysis of the sponge compression and packaging system, which will reduce the height of the sponge by 10 times, has been made. Soldiworks program was used to model this system. The structural analysis of the system was examined with the help of the widely used Ansys Workbench 18.1 program, that is, the stress, deflection and safety coefficient values of the system elements were obtained. As a result of the analysis, it was concluded that the designed system can be used safely in the compression and packaging operations of sponges up to 28 density.

Keywords: Foam Comprension and Packaging System , Finite element analysis, Structural Analysis, Stress Analysis

1. Introduction

Polyurethane raw material is an important parameter in sponge formation. If we look at the formation of polyurethane from a technical point of view, the formation process took place as a result of the reaction of polyisocyanate and polyol derivative with the catalyst. Among the properties of flexible polyurethane foams are that they have open cells, air permeability, elasticity

and light weight. Therefore, Flexible polyurethane foam is used in furniture, bedding, automobile seats and cushions, packaging materials, carpet cushions and many other applications [1]. Most of the mattresses used in homes around the world are usually made of polyurethane foam; A wide variety of different grades of soft polyurethane sponges are available for mattress production. Sponge made of polyurethane is also widely used in the health sector[2]. Approximately 95% of the world furniture manufacturing industry and 80% of the mattress manufacturing industry use PUR foam, either partially or completely[3].Polymeric polyurethane foams have an important use in various industrial applications in energy absorption and comfort mattress applications [4].

Density is one of the important properties that make up the sponge's character. High-density sponges are more elastic and more durable than low-density sponges. Although two sponges with the same hardness values feel similar, there is no doubt that the high density sponge will be used for a much longer time without collapsing. There are several topics to understand the quality of sponge. One of them is the appearance of the sponge. The sponge is defined as poor quality if its pores are large, its appearance is irregular, and the spacing is empty, but the smaller the pores and the more refined and homogeneous its appearance, the higher quality the sponge. Finally, tear strength is an important consideration in quality. In addition, the engineering properties of foam materials, their adaptability to meet the requirements of specific applications, their energy absorption capacity are preferred in a wide variety of commercial applications, including collision protection in automobiles. Plastic consumption in automobiles is increasing impressively, largely driven by the ever-increasing demand for fuel economy for automobiles. In the last decade, plastics have made up about 10% of a car's weight; The proportion of polyurethane-based plastic is approximately 21% of the total plastic parts in a vehicle[5]

For the reasons mentioned above, it is important to determine the mechanical properties of sponges, which have a wide usage area in many sectors [6] and it is believed that the mechanical properties of foams are important [7]. Marsivana et al. conducted studies on the performance of polyurethane sponges under different conditions. [8]. Demirel and Tuna examined the changes in the hardness and thickness values of sponges by performing fatigue tests on polyurethane foams of different densities and different categories. [9]. Studies on the past, present and future of sponge materials summarized by Gama et al. [10]. However, many studies have been carried out on the internal structure of the sponge and it has been stated that its internal structure is important. Ulrich conducted studies on the mechanical behavior of flexible polyurethane sponges produced from polycondensation of polyols with isocyanate. It has been determined that the sponges produced with this production method are open-celled, have high gas permeability, low density and low mechanical strength [11]. Yang, C. and S. Kyriakides worked on the multiaxial crushing of open-cell foams [12]. According to all these studies, after the sponges are cured, there are cells that are not fully formed inside. When these cells are not opened, they are revealed during use in the bed and sofa, causing collapse complaints after a certain period of time. Esim and Benzer designed a machine that would decrease the height loss, that is explained as sponge

fault, and normalize the structure by breaking the unbroken cells in the sponge and carried out their structural analysis [13].

The finite element method enables to detect unexpected design errors that may be encountered during the use of mechanical designs and components and to reduce these errors. Besides, by using solid models of systems designed with computer aided design (CAD), studies on performance and reliability analyzes of the structure can be carried out easily. Today, The finite element analysis is used in many engineering fields such as machinery, hydrodynamics, fluid, construction, aviation, electricity to medicine. Examples of these studies are machine design and analysis [14] vibration analysis [15, 16] and dental applications [17, 18].

As mentioned above, sponges are also used in furniture, construction, packaging manufacturing, mattress manufacturing and electronics industry. Since the sponge is produced in blocks in this way, various sponge cutting machines have been machine designed in order to bring it to the desired dimensions [19]. Despite the cutting process, it takes up a lot of space due to its volume. Therefore, it is necessary to produce the sponges in settlements close to the end user or to reduce the transportation costs. For this reason, there is a need to design a sponge compression and packaging system that will reduce the volume occupied by the sponge and reduce the cost of transportation.

Studies on such structures designed for sponge compaction and packaging are insufficient. In addition, in order to ensure the safety of the machine in the design of the sponge compression and packaging system, it was not found in structural analysis with the finite element method.

In this study, the design and structural analysis of the system that will provide sponge compression and packaging is presented. In order to make the analysis similar to the real system behavior, structural analyzes were made with the forces determined according to the properties of the sponge. According to the analysis results, the material and design used in the compression system were found to be simple, reliable and cost-effective.

The following sections of this study are as follows; The mechanical design of the compression machine forming the system is given in the second chapter. Then, the finite element analysisof Compresisin system and results and discussion are given in Section 3.4, respectively. Finally, the contributions obtained from the analysis results are included in the conclusion section.

2. Design of Compression System

Sponge; It is one of the most used flooring materials today and is available in different thicknesses and densities in the market. It can be used as a sponge block in furniture upholstery as well as in smaller pieces[7]. The production of block sponge is obtained by reacting a mixture of polyol and isocyanate. While this mixture acts as a liquid on the sponge casting belt, bubbles form after the reaction and the mixture expands. By expanding the liquid chemical, it is produced in the form of a rectangular prism with a height of 1300 mm, a width of 2100 mm, and a maximum length of

20 m. Due to the process, the width and height of the sponge are fixed, but the length of the foam block produced varies by cutting and sizing the endless block produced on the moving conveyor from the back. When foam blocks are needed due to their large size, the loss of time and cost in the procurement process harms both the manufacturer and the buyer. In this study, a sponge compression and packaging system has been developed in order to reduce the volume occupied by the block sponge.

As can be seen from the figure, the table, which compresses the block sponge by pressing method and reduces its height as much as possible, is designed to consist of a hydraulic system. The height of the sponge is compressed up to a certain point thanks to the 4 hydraulic pistons on the table, which consists of a hydraulic system that enables the sponge to be compressed. With the applied force, the height of the block sponge is reduced to approximately 1/10 of its own height.

Solid modeling of the pressing unit designed to compress sponges of different densities is as in Figure 1. In this study, the solid modeling of the compression and packaging unit was made with the SolidWorks program.
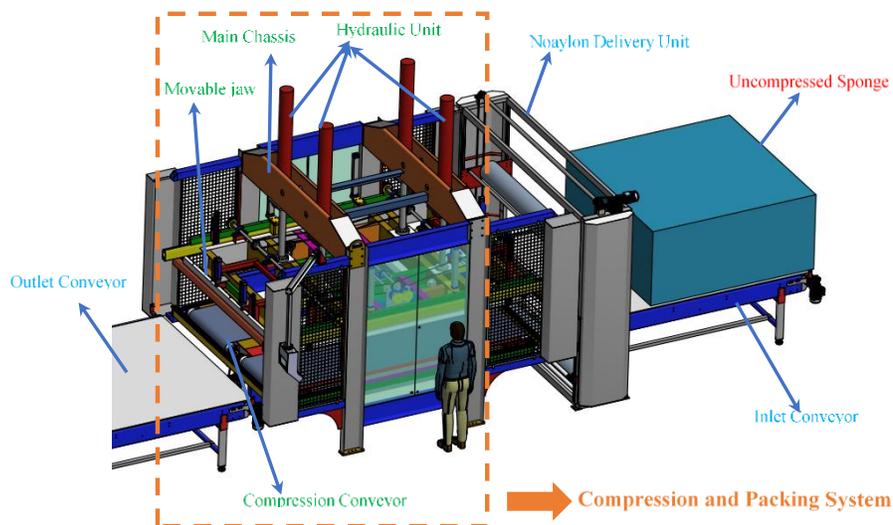

Figure 1. Sponge Compression and Packing System 3D model view

As can be seen in Figure 1, it is seen that there is a movable jaw on the compression machine and it is carried out with 4 hydraulic pistons (Diameter 100mm, Stroke 1300mm) in order for these jaws to compress. Hydraulic pistons are connected to the main chassis and are fixed on it. In order to prevent any contraction in the movable jaw, it is both bedded from 4 regions on the chassis and a rack gear system is attached to it. The dimensions of the foam block produced are 1200mmx2000mmx3000mm and there are two conveyor compression jaws at the entrance and exit of the system, and a belt-operated conveyor line in order to ensure the entry and exit of the product in the system. In addition, there is a nylon opening system for packaging with nylon after

being compressed for packaging purposes in the system. There are 4 nylon bonding units that allow the nylon to be bonded by giving heat after the nylon is compressed together with the nylon. Each of these nylon bonding systems is controlled by pneumatic pistons. In this study, analysis studies were carried out on the press part, where the system is important and critical, and the results obtained here are given. The press part of the system, which is considered critical, consists of 3 parts, and the detailed modeling of this part and its components are given in Figure 2.
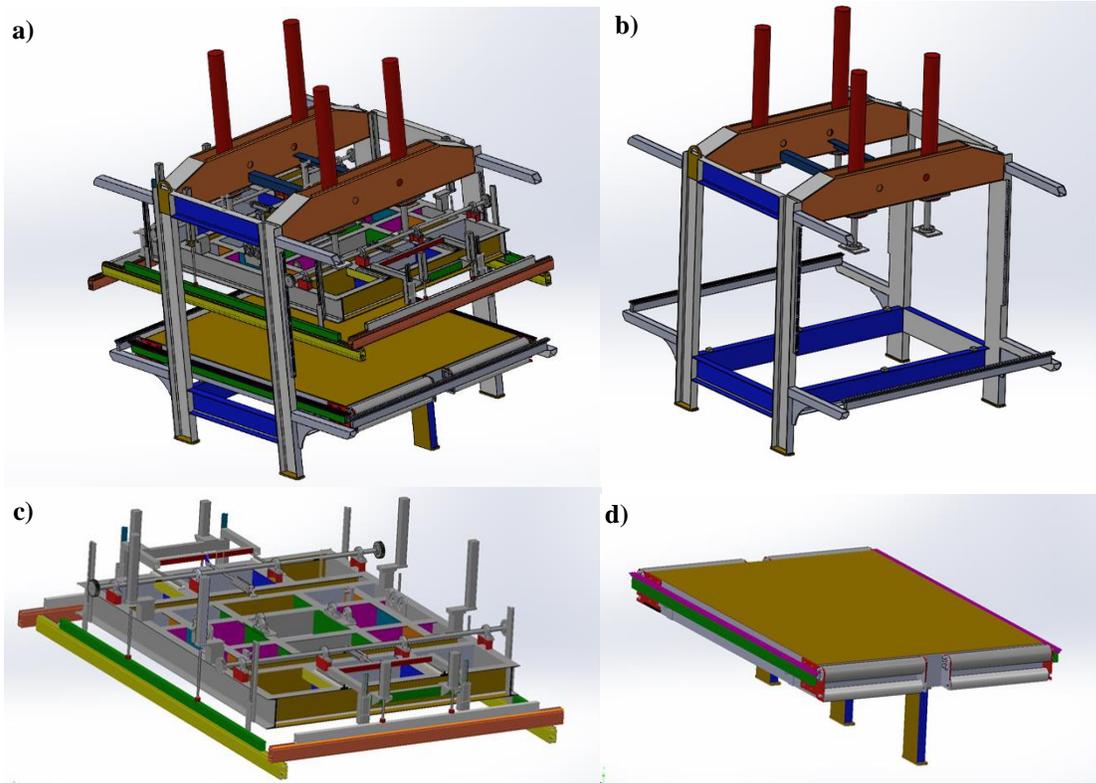

Figure 2. Detailed view of sponge pressing and its components a) Full system b) Main Chassis c) Movable Jaw d) Conveyor

The hydraulic pump used in the system is a gear pump type operating at 200bar. The capacity of the hydraulic oil tank is determined by considering approximately 100 liters of oil and pump pressure value (200 bar), hydraulic cylinder diameter and maximum piston force (F_p) in the hydraulic system. F_p was calculated as 320000N considering the sponge compression ratios from the experimental study [13] according to the hardness of the sponge to be crushed in our previous study, and all analyzes were carried out according to this value.

As can be understood from Figures 1 and 2, the compression machine consists of many components. The fact that the system consists of many components and geometrical differences increases the complexity, which makes a theoretical solution difficult. In such cases, approximate solution methods that give results close to the exact solution are preferred. . One of these methods is the most widely used finite element method. In this method, the system is divided into regular geometric small elements and transformed into a structure called "mesh" operation in the literature. In this defined mesh structure, the solution is realized with various assumptions. The larger the number of elements in the finite element method, the more difficult the solution, but more precise results can be obtained. Therefore, in this study, SolidWorks program was used to create the solid model of the compression and packaging machine. ANSYS Workbench program was preferred for structural analysis.

3. Finite Element Analysis of Compression System

Structural analysis of the designed structure is considered an important step during the design. Therefore, the purpose of structural analysis is to determine whether the system is in safe and secure conditions by determining values such as deformation stress and safety factor. The basic assumption in structural analysis is that the system is linear and any nonlinear situation in the system is neglected. In order to perform the structural analysis of any structure, general finite element processing steps are applied in the compression and packaging system. The analysis process performed by ANSYS WORKBENCH is as follows:

The components that make up the sponge compression and packaging system and their assembly were created using the Solidworks program. All models of the solid designed foam compression and packaging system were transferred to the ANSYS Workbench 18.1 program. All contact definitions and boundary conditions are defined with this program. In the analysis of the sponge compression and packaging system, the groups moving together were combined and the main frame + movable jaw, conveyor was designed as a group. These models were analyzed separately and the results were given. In addition, in the case of all components together, the analysis was performed and the results were presented

The analyzes were carried out with a computer with Intel Core i7-2600 CPU @ 3.40 GHz, 32 GB RAM. It was fixed from the ground contacting surfaces of the compression machine. Analyzes were made by applying the load to the surfaces of the conveyor and upper jaw that contacted the sponges. The main components that make up the compaction machine and their subcomponents are in contact with each other. Therefore, since the surfaces are inextricably linked during the analysis, the contact type is defined as BONDED. Solid186 (linear tetrahedral solid element) and solid187 (linear cubic solid element) types were used as element types. The dimensions of the elements are adjusted to an average of 20 mm. Three different models were preferred in the analyzes and the mesh and node numbers of these models are given in Table 1. In order to show the mesh structure in the system, the whole system divided into elements is given in Figure 3.

The same mesh structure is used in different models of the structure, but the number of elements and nodes varies according to the absence of elements on it. Here, in order to determine the performance of my system, 3 different modeling and analyzes of the load as separate components in the system and as the whole system were made. It is assumed that the materials used in the analyzes are homogeneous and isotropic. Two different materials, St37 and St52, were chosen as materials in the design. The mechanical properties of this material are given in Table 2.

Table 1 Number of mesh and nodes of model types

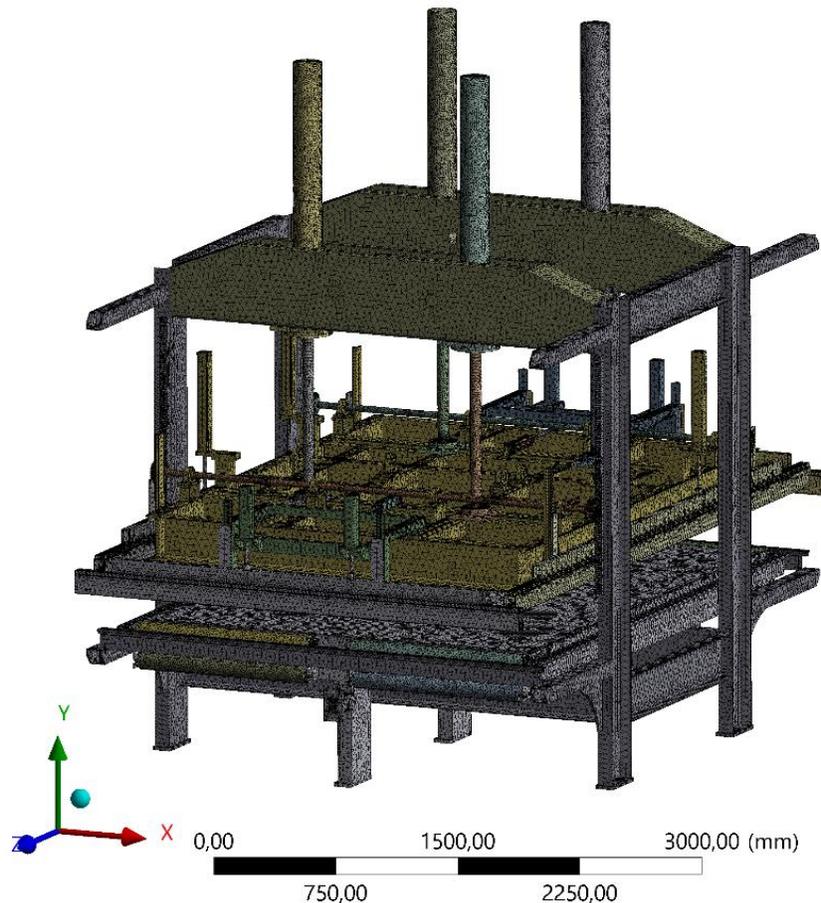| Model	Node number	Mesh number
Model 1 (Main Chassis + Movable Jaw)	2731871	1457175
Model 2 (Main Chassis +Conveyor)	1605097	835611
Model 3 (Full System)	3481012	1839732

Figure 3. Sponge compression and packaging system mesh view

Table 2 Mechanical properties of the materials

Material	Density	Young Moddulus	Poisson Ratio	Yielding Stress (Tensile)	Yielding Stress (Compressive)	Ultimata Tensile Stress
St37	7850 kg/m^3	210 GPa	0.3	250 MPa	250 MPa	460 MPa
St52	7870 Kg/m^3	210 Gpa	0.3	602 MPa	522 MPa	540 MPa

After the compression machine is seperated into elements, the definitions of contact processes between the elements are made. In the system, many structures have been defined according to their communication status and working conditions. The view of the boundary conditions formed according to the operating state of the system and its relations is given in Figure 4. Since the bottom of the machine is in contact with the ground, these places are defined as fixed supports.
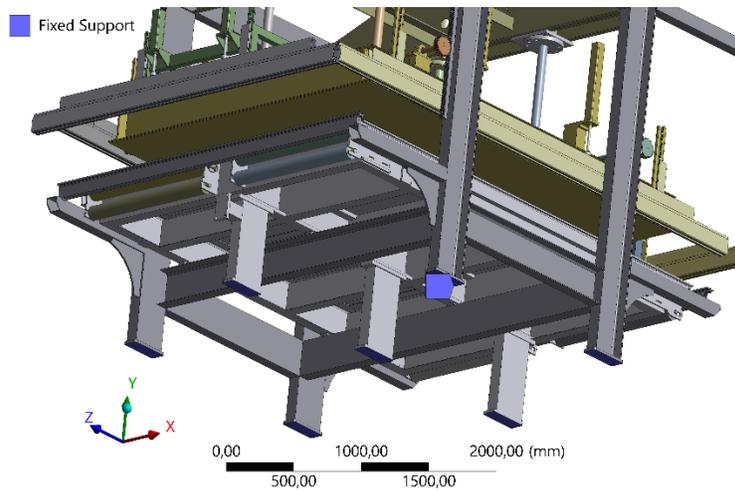

Figure 4. boundary condition of system

4. Result and Discussion

As mentioned aboveAnsys Wotbench simulation package was used to determine the stress distribution and the amount of deformation after mesh formation in sponge compression and packaging system. The stress distribution of the system was determined according to the maximum strain energy hypothesis (von-Mises) in the package program. In addition, in order to evaluate whether the model is safe and secure, the safety coefficients of the system were calculated and the obtained results were presented. While performing the analyses, analyzes

were made on two different materials and stress and safety coefficient results were obtained under the same loading conditions. Considering the model consisting of the upper jaw and the main chassis as Model 1, it is assumed that a load of 320000N is applied in the +y direction to the surface where the upper jaw comes into contact with the sponge, and the structure is fixed from the base touching the ground. In addition, for guiding, the contact between the gear and the rack gear is defined as no separation, all other contacts are defined as bonded. Under these conditions, the results of the von missese stress and safety coefficients in Model 1 according to the St37 and St52 materials of the structure are given in Figure 5.
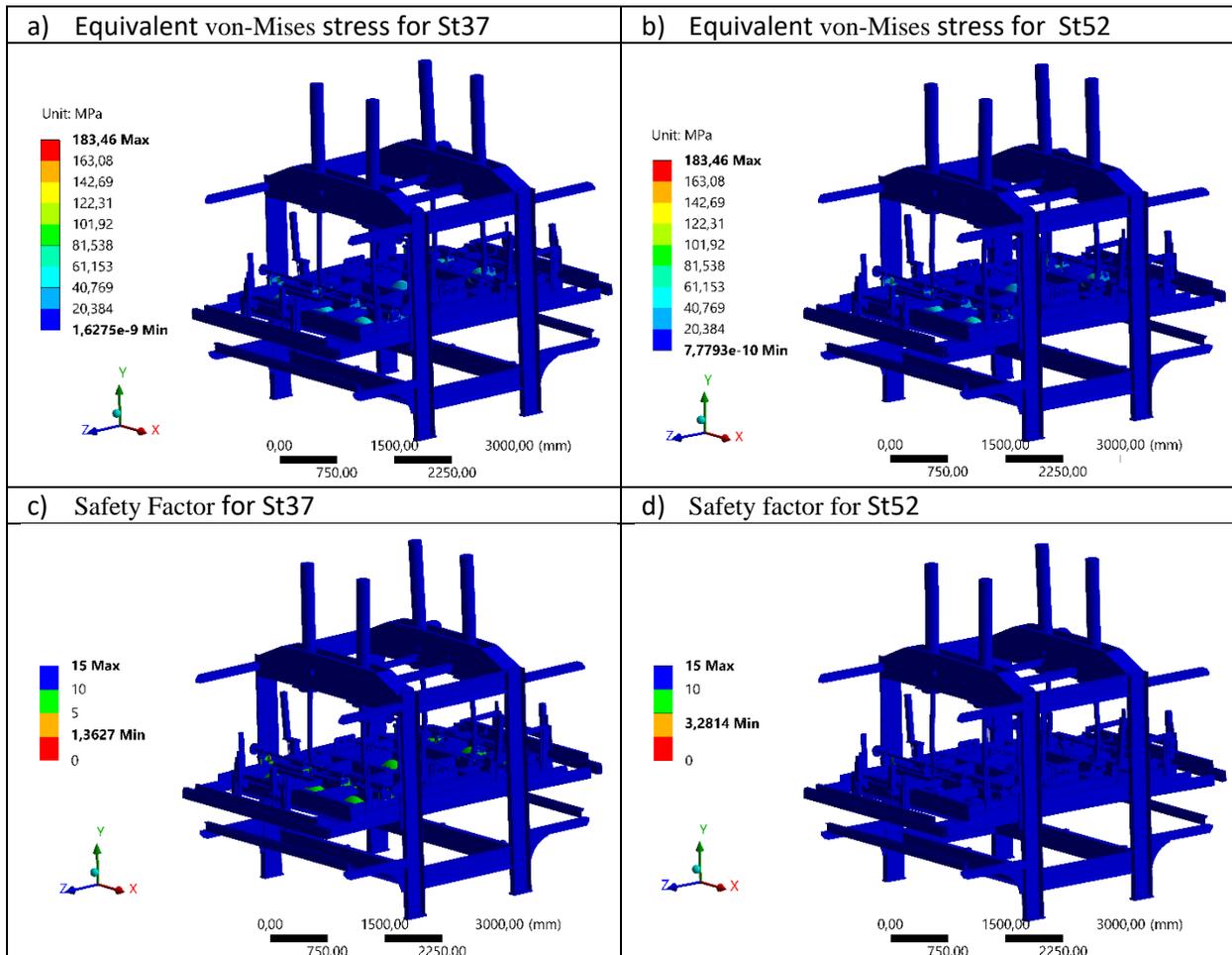

Figure 5. Von Misses stress and safety coefficient changes in the system for Model 1

As can be seen from the figure, the maximum stress values for St37 and St52 were 183.46 MPa. When compared in terms of safety factor, it was determined as 1.367 for St37 and 3.2814 for St52. The reason why the tensile value is the same here is due to the same elasticity and poison ratio in both materials. Therefore, the distinguishing situation here is the safety factor, and the system is safer than the St52 material. Again, in the case of compression in the system, a reaction force occurs on the conveyor in the opposite direction of the upper jaw. For this reason, in Model 2, which consists of the conveyor and the main chassis, the system was analyzed by applying a force of 320.000N in the -y direction on the conveyor. In the same way, fixed support is provided from the 3 legs of the conveyor on the main chassis. Under these conditions and loading conditions, the stress and safety coefficient results in the system are given in Figure 6.
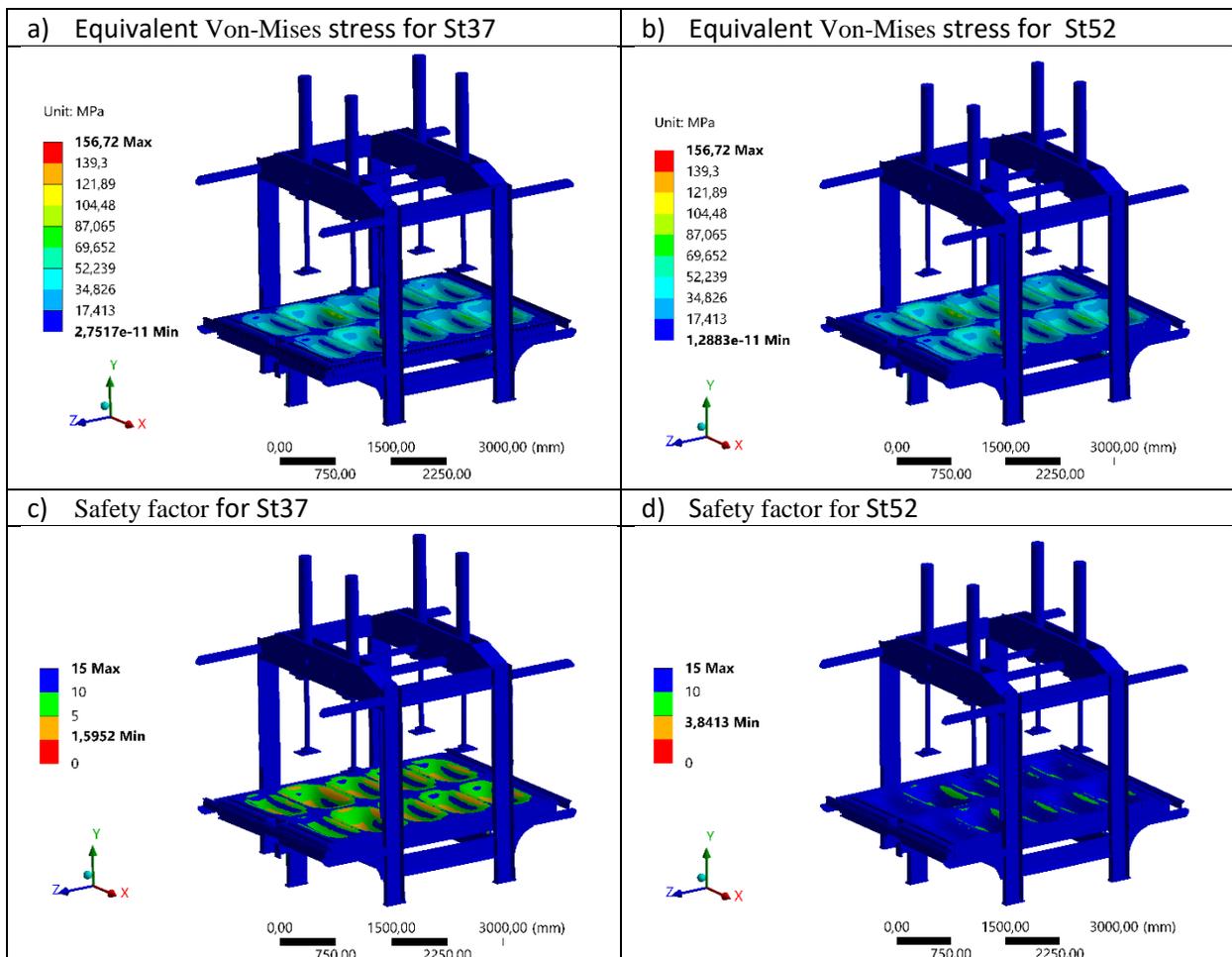

Figure 6. Von Misses stress and safety coefficient changes in the system for Model 2

As can be seen from Figure 6, the stress values occurring in the system for both materials are calculated as 156.72Mpa and the safety factor is 1.592 for St32 and 3.8413 for St52 material. It can be said that the system is safe and secure for the St52 material in the same way in Model 2. Since the conveyor and the upper jaw will be used at the same time in real operating conditions, on Model 3, where the entire system is taken into account, 320,000N force was applied to the upper jaw of the machine in the +y direction and 320,000N force was applied to the conveyor in the -y direction, the main chassis bases and the conveyor bases were fixed to the ground. The stress and safety coefficient results in the system under these boundary conditions are given in Figure 7.
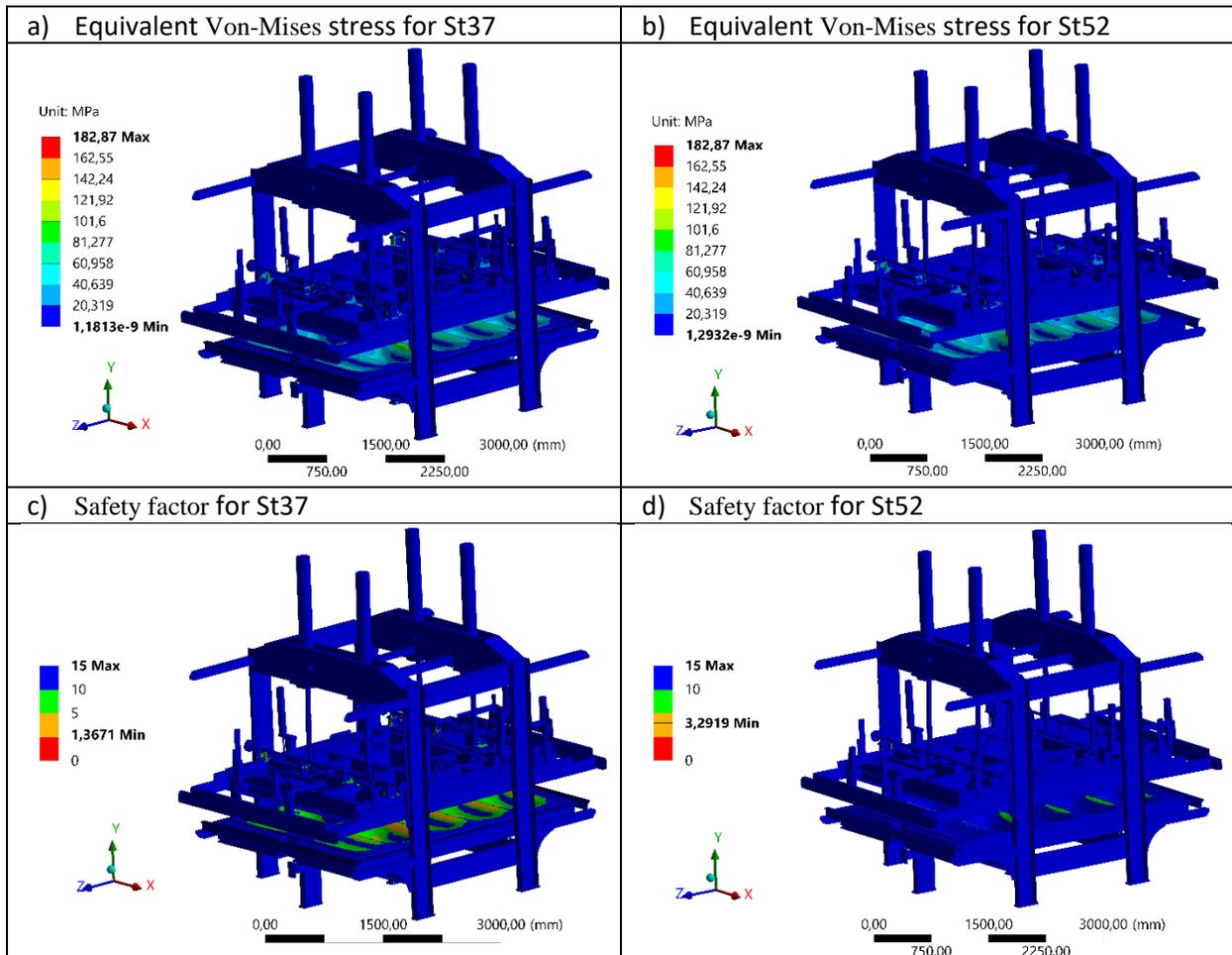

Figure 7. Von Misses stress and safety coefficient changes in the system for Model 2

According to the results, the maximum Von Misses stress value was 182.87 MPa for two different materials. When the safety coefficient results were evaluated, it was 3.2919 for St52 and 1.3671 for St37.

According to these results, when a general evaluation is made, it can be said that the machine for St32 is not safe for all 3 models. However, considering that the system is manufactured with St52, it can be said that it is safe in 3 different situations. When the results are evaluated, it can be said that the compression machine and its components are safe and secure for 28 density sponge compaction and packaging. In addition, considering the compression of sponges with low hardness, the force values to be applied in the system will be lower. In this case, it can be said that the reliability of the system will increase even more. In order to increase the safety and security of the systems, it is necessary to either change the material of the components or change the geometric structure. Here, the design of the system has been improved by changing the material.

5. Conclusion

In this study, the design and structural analysis of the sponge compacting and packaging machine was carried out to reduce the sponge volume in order to reduce the transportation costs of the produced sponges. In the first part of the study, the system design required for compression and the calculations of the force and hydraulic system to be applied on it are given. In addition, in the system design, the structural behavior of these components was not examined by making separate modeling of the compression machine, the main chassis conveyor and the upper jaw. For this purpose, a 3D model was designed for structural analysis. Structural analysis of the compression system was carried out using the finite element method. In the finite element analysis, linear static analysis was performed in the Ansys Workbench package program. Thus, the maximum Von Misses stress locations, the results of the safety coefficients and the necessary optimization locations on the system were determined.

One of the important features of this study is to analyze the mechanical behavior of the system by analyzing all the components of the compression system and the main chassis, conveyor and upper jaws that make up the machine separately. Thus, the determination of safe and secure operating limits for both the whole system and the component has been realized. The results obtained provide useful information in terms of compression and packaging machine design for companies producing sponges. In addition, this study is useful and realistic in terms of determining the materials to be used in the production of sponge crusher machine. It is also possible to produce the parts that make up the system at more appropriate scales with design optimization techniques. In addition, with topological optimization, the results can be improved according to fatigue analysis in future studies.

The results obtained in this study make an important contribution to the determination of the mechanical behavior of the compression machine, and it is possible to say that this study can be applied in real studies and will shed light on similar studies and literature.

6. Acknowledge

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