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Optimization of manufacturing process of stainless steels by biomimetic approach and increasing sharpening performance

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ABSTRACT

In the present study, a biomimetics approach were used in all design stages of the improved bionic circular blade design. Finite element method is used in optimization. The analyzes were repeated theoretically until the best result was obtained. Samples were produced using the best obtained results, then tests were carried out. The heat treatment step was removed from the manufacturing flow of the bionic circular blade resulting an important cost reduction about 60% in the product. The bionic circular blade is designed to operate without sharpening. As a result, a patent application has been filed for the bionic circular knife developed within the scope of the study. Intellectual property right of the research was obtained with the patent number 2017/12077. The main results obtained in the present paper can be summarized as follows: the heat treatment step was removed from the manufacturing flow of the bionic circular blade. Thus, the 7-stage manufacturing flow followed for the standard circular knife has been reduced to 4 stages for the bionic circular knife. Due to the removal of heat treatment processes, the production time is decreased by 40%. For the improved bionic circular blade, a different material and optimized dimensions are used. As a result, material savings of around 76% is achieved with a material coast reduction of about 60%. The bionic circular blade is designed to operate without sharpening. For this reason, blindness problems currently experienced in the designed blade are not experienced. Research continues to increase the 10-hour application time achieved without the need for sharpening.

Keywords: Biomimetic; Bionic Knife; Computer Aided Desing; Application; Stainless Steel

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1. Introduction

Biomimetic is expressed as a complete or partial imitation of living structures in nature [1]. Researchers have been inspired by nature in every period and conveyed this to the designs they are working on. With the transfer of living structures in nature to researches in the technical field, ergonomic, technically more resistant structures that have been presented to human use have emerged.

It is seen that many of the biomimemis technically used structures consisting of the words "bios" meaning life in Greek and "mimesis" meaning imitation appear as inspiration in the designs made. These examples are found in the construction, software, health and automotive sectors. Biomimetics also has applications in the technical field. Biomimetics was used in the design of high-speed trains, aircraft production and submarine design [2].

In this study, it was studied on the application of biomimetics to cutting tools. The production method of the currently used blade has been examined and the problems encountered during its production have been identified. The need for a new product design has been identified. Based on the current problems, a new blade design has been made. Biomimetic was used during the design of the new product. The data used in the study were obtained from a company. The data obtained consists of both the data observed during the operation of the currently used blade and the data obtained during the operation of the designed blade. Performance values were obtained as a result of the designed bionic circular blade working on the production line. The performance values of the blade used are compared with the performance of the blade currently used.
In the present study a biomimetics approach were used in all design stages of the designed bionic circular blade. Finite element method is used in optimization. The analyzes were repeated theoretically until the best result was obtained. Samples were produced using the best results obtained and then tests were carried out. The heat treatment step was removed from the manufacturing flow of the bionic circular blade resulting an important cost reduction about 60% in the product. The bionic circular blade is designed to operate without sharpening. As a aresult, a patent application has been filed for the bionic circular knife developed within the scope of the present study. Intellectual property right of the research was obtained with the patent number 2017/12077.

2. Literature

2.1. Biomimetics

The concept of biomimetic appears in the literature as biomimicry, bionic, biomimesis. Biomimesis consists of the words 'bios' meaning Greek life and 'mimesis' meaning imitation. Although biomimesis may seem like a new concept added to the literature, when we examine the past of mankind, it seems that dreams of flying like a bird, swimming like fish, are based on the past. Biomimetic is defined as the complete, partial or complete imitation of a living creature in nature, color, texture, function or science [1]. The concept of biomimetic has become popular since the late 1950s. Another frequently used term 'bionic' was voiced by Jack Steele in the 1960s. As a biomimetic word, it was defined in 1974 as Webster's dictionary as 'the study of the formation, structure and function of biologically produced substances and materials, and biological mechanisms and processes' [3].
Between 1985 and 2005, R. Bonser examined patents containing the terms 'biomimetic', 'bionic', 'Biologically inspired' in America [4]. In the study conducted by R. Bonser, it has been shown that the studies carried out inspired by nature have become widespread in the last two decades and very successful results have been achieved in industrial applications.
The application areas of biomimetics can be summarized as follows: Human beings have been inspired by nature throughout history, and have transferred the working principles of natural mechanisms in nature to their research in their designs and designs. Xia have studied and detailed biomimetics in four classes according to their application areas in their studies on biomimetic designs [5]. The classification made in Fig. 1 is given**.**

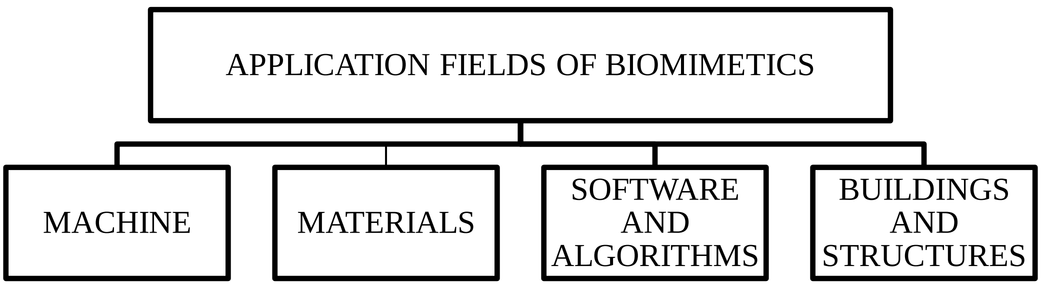

Figure 1. Classification of biomimetics by application areas [5]

2.2. Material structure

In this sub-section, the material properties and structures used in the present study are included. When the basic properties of steels are examined, the results are as follows [6]: When steels are brought to certain temperatures, they get shaping feature (such as forging, rolling and pressing). Steels suitable for chemical composition and internal structure can be cold formed by methods such as pressing and rolling. Together with the chip removal process, it can be brought to the desired shape and surface smoothness. They have the chemical composition to be combined with the welding process. Most of the steels are suitable for enameling with various methods, metal coating, painting and plastic materials.

Some of the German and American standards were inspired in the preparation of the Turkish Standards Institute (TSE). Therefore, some conditions valid for German standards and others for Americans are also valid for TSE [7].

In order to facilitate the examination of steels, classification has been made by using common features. While classifying steels, one type of steel was found in another type of steel. For this reason, it is not possible to set a definite limit while classifying and to separate one steel type completely from the other steel type [8].

Steels are used in the fields of machinery producing industries, in the production of constructions, in precision mechanical parts, in the production of mass-produced parts such as pins and apparatus in the automobile industry.

The material used in the study belongs to the stainless steel group. Stainless steels contain at most 1.2% carbon and at least 10.5% chromium. By adding different elements to the structure of stainless steels, alloys with different properties are obtained. Corrosion resistance is increased by increasing the chromium ratio in the structure of the material or by adding elements such as nickel and morib. Apart from these elements, many different elements form different alloys by giving positive results in stainless steels. In this way, users of stainless steel find the opportunity to choose alloyed stainless steel suitable for them.

2.3. Cold deformation method

Cold forming method does not require heating, it increases the properties such as strength, fatigue and wear through hardening, the similarities of the samples coming out of the mold and their good usability. Besides its benefits, it also has some disadvantages. In some of these, intermediate annealing may be required to increase the ductility decreased by hardening, undesired residual stresses may occur and the tensile strength of the product may differ from the beginning [9].

In the present manuscript, it is aimed to remove the heat treatment stage in the manufacturing process of the circular knives. For this reason, the material thickness used has been changed. With the cold forming method, some hardness was added to the material and the product was obtained with the designed mold. Twisting was done to the piece prepared by applying a load of 20% of the required load amount for the pour point of the material.

The most important problem that occurred during the heat treatment to increase the hardness of the blades was found to be the flatness problem occurring in large parts of the surface area. The form formed on the material by the cold forming method gives the material a hardness of 42-45 HRC without the need for heat treatment, and with this hardness, the product shows the desired performance values. The flatness problem experienced during the production of the product is also eliminated. With the solution of this problem, serious earnings were obtained in terms of labor and economy.

3. Design and experimental work

The current section is mainly focused on the working environment of the circular blade, the characteristics of the product that the blade is designed to cut, and why the design of the bionic circular blade is necessary?

The current standard circular blade examined in this study is used for cutting the stony part of the chicken. It is defined as a stony muscular stomach. There is a strong muscle structure in the stony area. With the coordination of these muscles, the breakdown and grinding of the feed is provided. In Fig. 2, the image of the stony cut with standard circular blade is given.

3.1. Circular blade design

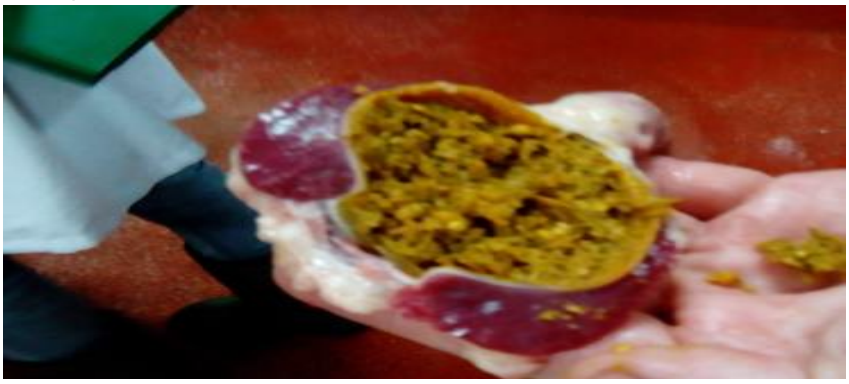

Figure 2. Stony cutting using the existing blade

The foreign bodies that come out during the cutting of the stony rocks are called solid matter. When the stoniness of the chicken is examined, it is observed that there are various solid substances in nature. Different types of plastics, lead, nails, bolts are some of them. In Fig. 3, examples of solid matter coming out of the stony after cutting are given. In Fig. 4, the path followed by the machine for cutting the stonework is given.

Figure 3. Solid materials coming out of the stony after cutting

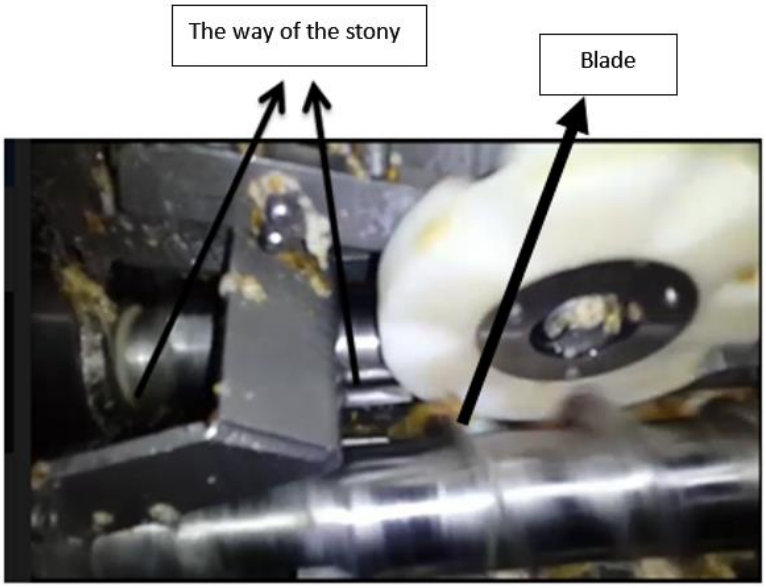

Figure 4. The path of the stones on the machine for cutting

The cutting process takes place as follows; the stoneworkers move sequentially in the machine with the help of a spiral and come to the area where the blade operates. Here, slits are opened in order to discharge solids on the rocks. As a result of the cracks opened, the solid materials in the stony rocks are cleaned in the next stage. It has been observed that blunting occurs due to the contact of the blade with the solid substances in the stonework and the foreign materials coming out of the stony during the working. As a result of blunting and deformations occurring in the cutting edge of the blade, the desired slots cannot be opened on the stony. However, solids in the stony are not sufficiently cleaned. This causes extra processes to be removed for the removal of solids in the rocks. As a result of the working, the standard circular knife that is blunted and deformed is removed from the machine and sharpening is performed. Instead of the standard circular blade that is blunted and deformed, the standard circular blade, which has previously been sharpened as a spare, was installed and production continues without disrupting production.

Solid materials existing in the stony cause the failure of the blade. With this situation, the desired slots cannot be opened to the stony areas. When the standard circular knife used in the current situation cannot achieve the desired cut, the knife is removed from the machine and sharpening is performed. Production is continued using the standard circular blade, which is new or previously sharpened.

The process of removing and replacing the standard circular knife for sharpening causes loss of time in production. This situation is repeated many times during a day's working period. The idea has emerged that a new blade design is needed to eliminate the sharpening process to eliminate losses that occur during production and the blunting that occurs after processing the blade. Within the scope of the thesis, data obtained from bionic circular blade design and a mold making for the production of the designed bionic circular blade and the operation of the bionic circular blade are given.

3.2. Standard circular blade design

Within the scope of the study, the circular knife, which is studied, has been named as standard circular knife (SDB). In this section, material properties, process steps and manufacturing problems that occur during the production of the knife are given. In Fig. 5, the formed solid model of the standard circular knife is given.

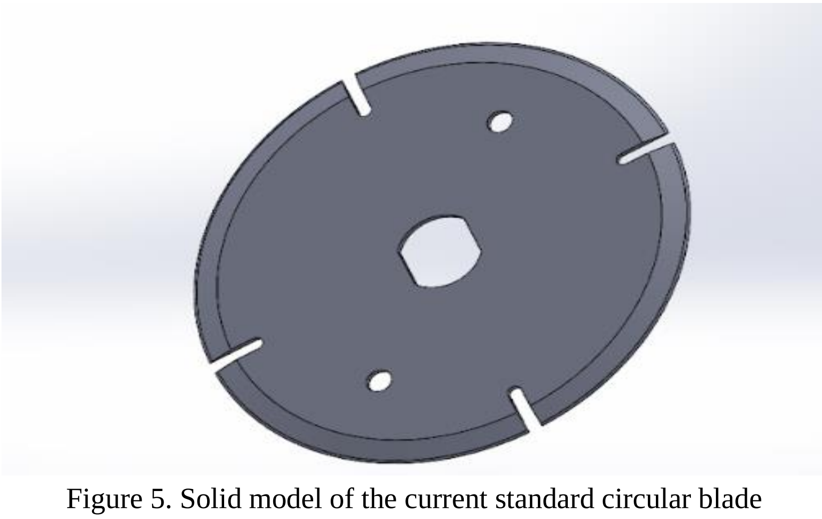

Figure 5. Solid model of the current standard circular blade

The current standard circular blade should be resistant to corrosion by the area it operates. For this reason, it is a prerequisite that the knife used in the present situation has a stainless feature. The preferred material falls into the stainless steel group. Currently, 1.4034 materials (EN X46Cr13 and AISI 420) have been used. The chemical composition of the steel used in Table 1 is given.

Table 1. Chemical composition of 1.4034 steel [8]

C (%)	Si (%)	Mn (%)	Cr (%)	P (%)	S (%)
0.40-0.50	1.0 max	1.0 max	12.5-14.5	0.045 max	0.030 max

1.4034 steel is included in both stainless steel and hot work tool steel group due to its chromium content. These steels are classified as martensetic stainless steels with their hardenability feature. 1.4034 steels are used in many areas such as scissors, table knives, roller bearings, bridge supports and medical implants.
The production stage of circular knives includes the processes listed in Fig. 6. These processes emerge as factors affecting production costs. In the proposed study, it is aimed to save production, labor and material by reducing these processes.
The manufacturing steps applied during the production of the standard circular knife are given in Fig. 6.

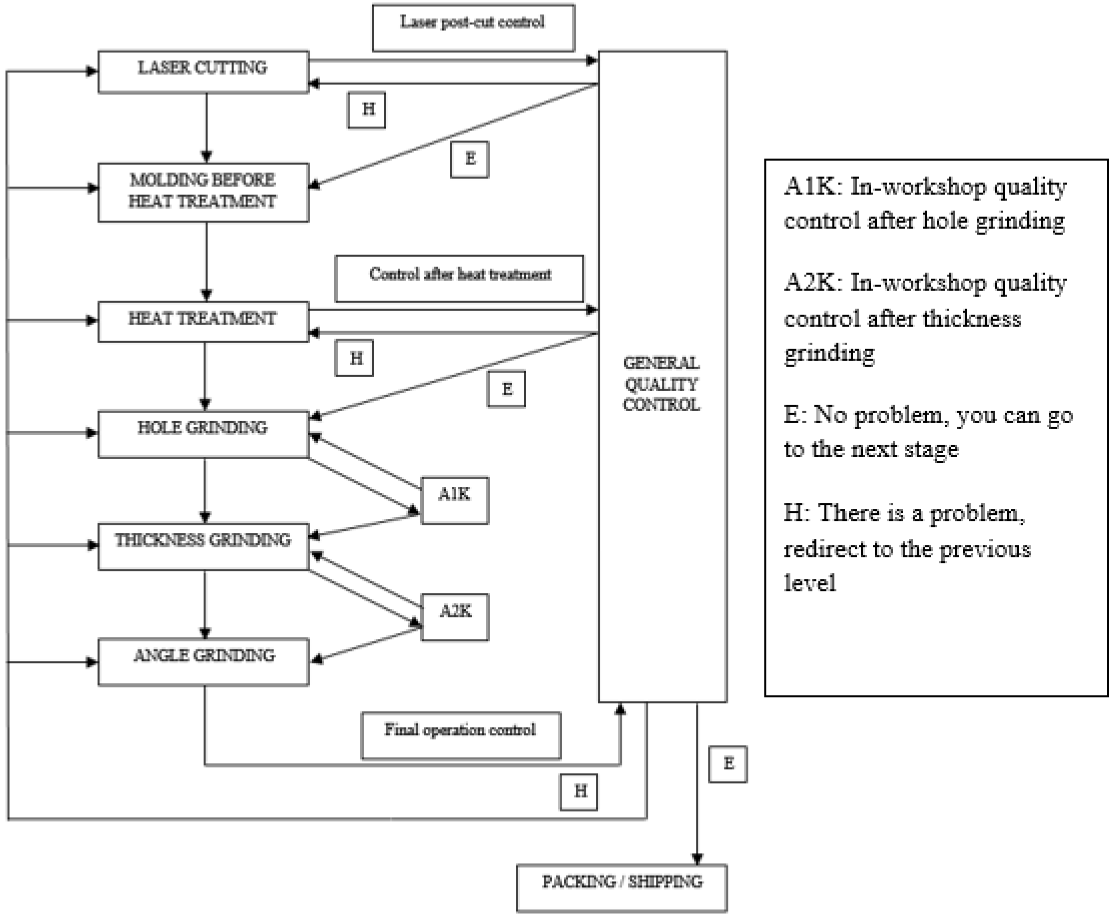

Figure 6. Production steps for the standard circular blade (SCB)

Manufacturing processes such as machining, heat treatment and finishing are applied in the production stages of SCB. The proposed bionic circular blade aims to shorten these processes, remove the heat treatment stage and reduce costs. The problems encountered during the production of SDB are examined below.
The manufacturing process is started by cutting the products in laser cutting according to the designed technical drawing. The purpose of this process is to prevent formal deformations in the material during the stage of giving hardness by bringing it to a certain temperature (Waste, secretion, etc.). Materials coming from laser cutting are subjected to molding process before heat treatment. The product whose molding process is completed is directed to the heat treatment stage. The problems first appear in the heat treatment stage. The problems in the heat treatment stage are examined in three classes:

1. Molding phase before heat treatment
    1.1. Products are not molded according to the specified molding criteria
    1.2. The molds used do not have the desired flatness properties.
    1.3. Incompatibility with the dimensional properties of the product
2. Heat treatment phase
    2.1. Flatness problem

2.2. Material being multiplied during heat treatment
2.3. The product resulting from the heat treatment furnace does not get the desired hardness value
3. Post-heat treatment phase
3.1. Implementation of the hammering process to correct the products coming from the heat treatment as a result of waste.
3.2. Scrapping of non-waste materials

Products from cutting are molded according to the determined molding steps. Experiments have been made for molding criteria. As a result of these trials, the parameters to be followed have been determined in order to prepare the molds in a suitable way. If the determined molding criteria are not followed, it is possible to encounter flatness problem in the products after heat treatment. In order for the products to be molded properly, the support elements shown in Fig. 7 need to be used during molding. The mold structure of the products that are molded according to the determined molding processes can be disrupted as a result of problems occurring in heat treatment. When the molds deteriorated after the heat treatment were examined, it was determined that the products came out of the mold and dispersed. This situation causes the flatness problem in the products to reach serious dimensions. It is necessary to spend extra time and labor to solve the flatness and distortion problems that occur. However, there are delays in the production time of the product and the manufacturing time designed for the product is more than expected. In Fig. 7, the image of the products that are molded with the mold process determined for the product is given.

Figure 7. Mold molded according to the defined molding parameters

As a result of the malfunctions occurring in heat treatment furnaces, the products coming from heat treatment have problems. This problem is observed as follows. The problem encountered is related to the hardness values of the products coming from the heat treatment. In the created technical drawing, the hardness value that the parts should take is determined. As a result of the malfunctions in the heat treatment furnaces, it was observed that the hardness values of the products coming from the heat treatment were less or more than the specified value. In these two cases, the products are sent to the heat treatment process or tempering again. If the desired hardness values are not obtained, this process is operated again. With these observed negativities, there is a delay in the production time determined for the products. This is a factor that affects production time in a serious situation.

After the heat treatment, after the hardness control products come to the production where the problem is not detected, extra processing is done to solve the flatness problem caused by the molding and heat treatment process. With the hammering process, the flatness problem of the products is tried to be eliminated. During the operation of this process, extra time and labor arise again. The image created by hammer marks after the hammering process on the product is undesirable. The standard circular knife on which it is worked is used in the food industry. Hammering process is applied to solve the flatness problem of the product. Traces formed on the standard circular blade after the hammer process create areas open to bacterial growth. In order to remove these hammer marks, a separate process has to be applied again. If the desired surface quality cannot be achieved as a result of the applied processes, the products are separated and the production process followed for the standard circular knife is operated again. With the repetition of these processes until the desired result is achieved, production times are delayed.

In Fig. 8, the image of the completed product, which does not encounter the flatness problem caused by heat treatment, is given. In Fig. 9, the surfaces with and without the hammering process are given after heat treatment. In order to overcome the flatness problem, the products were subjected to the hammering process. As a result of the process, a visual situation has occurred in the products as in Fig. 9-b. Images formed on the blade after hammering are undesirable as a result of manufacturing the product.

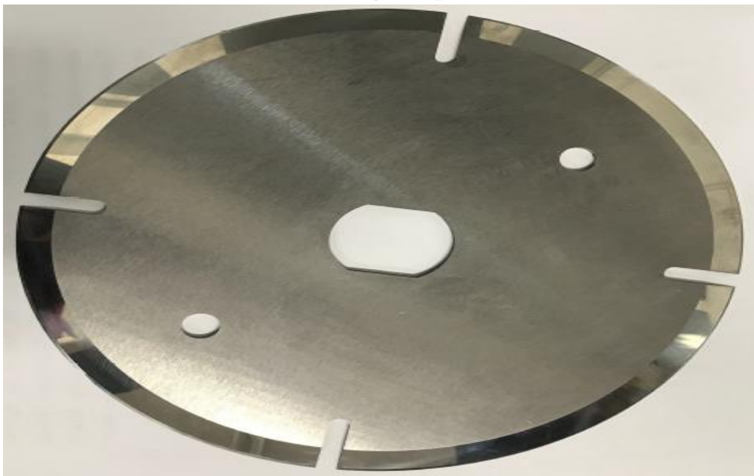

Figure 8. The image of the blade that has not been produced without flatness problem.

a) **b)**

Figure 9. Surface and non-applied surface images of hammering operation as a result of heat treatment process. a) surface without hammering process, b) Surface where hammer process is applied

In standard circular knives whose visuals are given, the frequency of heat treatment problems and extra time and workmanship are spent in the solution of the problem, the delays in the delivery times of the products increased due to the product's delays in the delivery times, with the separation and reconstruction of the products after the hammer process.

3.3. Mold design for bionic circular blade

During the production of the standard circular blade, problems causing the production flow and manufacturing time to increase have been identified. Ishikawa diagram was used to determine all the possible causes of these problems and the relationship between them. The root causes of the problems that increase the production time of the product are investigated by giving the diagram known as the fishbone diagram in Fig. 10.

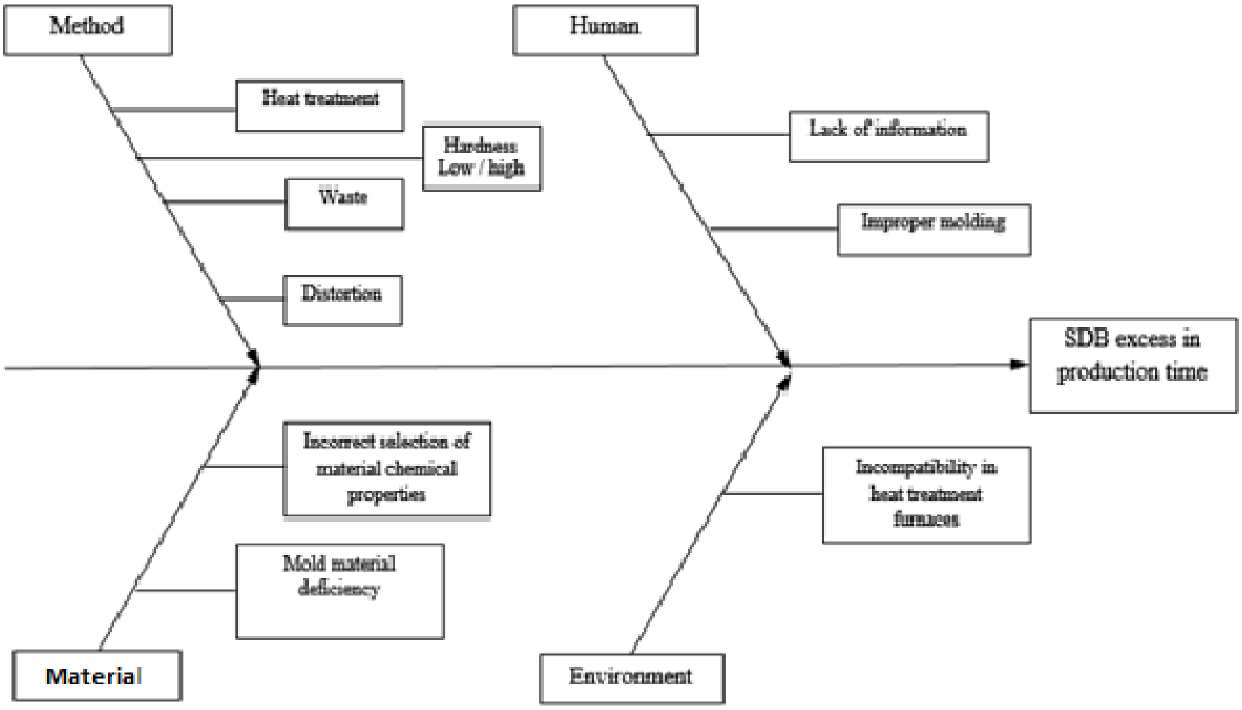

Figure 10. Fishbone diagram examining the excess production time

In Fig. 10, the factors causing the production time of the product are determined. It has been observed that the stage where the problem occurs in the manufacturing flow is the heat treatment stage and the problems occurring here significantly affect the flow of the manufacturing.

It has been determined that the problems experienced in these three sections negatively affect the production flow and cause the production process to increase and cost increases.

In order to eliminate these problems affecting manufacturing processes, a new blade design that would work in this field was needed. The designed blade is intended to be used for mass production. It was decided to make molds to minimize the production costs for the product and to produce the product in series. Information about the bionic circular knife and the bionic circular knife designed in this section is given.

3.4. Manufacture of designed bionic circular knife

The manufacturing of the designed bionic circular knife was made different from the manufacture of the standard knife. The problems encountered during the production of the standard blade increased the need for a new blade design. The problems that occurred caused serious losses in workmanship, material and production time.

The stages that cause problems in the manufacturing flow of the current standard circular knife have been determined. A design is considered in which there are no such stages, and as a result of the operations, the final product shows the same features as the current product. The manufacturing stage, where significant problems were encountered during the manufacturing flow, was observed as heat treatment. For the designed product, a manufacturing flow was created without heat treatment process. The hardness value of the blade should be in the area where the product operates. It has been observed that it is necessary to give the part a certain level of hardness by a method other than the heat treatment process. Cold deformation method has been used to add hardness to the designed product. The bionic circular knife designed to be used for this method has been determined as 0.60mm before the process. In Fig. 11, no process has been made and a bionic circular knife image ready for twisting is given.

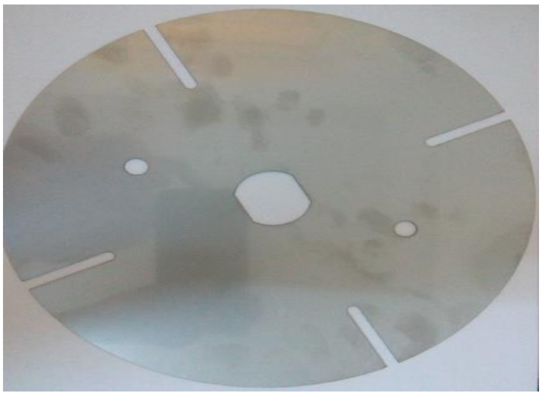

Figure 11. Laser cut piece for bionic circular blade

The material to be used for the bionic circular blade has been used differently than the current standard circular blade. The material of the bionic circular blade is determined as 1.4301 stainless steel. The chemical composition of 1.4301 stainless steel is given in Table 2. While determining the thickness of the material to be used for the designed bionic circular knife, it was taken into consideration that it is easy to find on the market and that it provides convenience during twisting. For this reason, the material thickness to be used has been determined as 0.60mm. The chemical composition of 1.4301 stainless steel material is given in Table 2.

Table 2. 1.4301 stainless steel chemical composition [8]

C (%)	Mn (%)	P (%)	S (%)	Si (%)	Cr (%)	Ni (%)
0.08 max	2.0 max	0.045 max	0.03 max	0.75 max	18-20	8-10

After determining the material to be used and the thickness of the material, it has become necessary to form the surface part of the bionic knife raw material, so that the bionic circular blade is the same as the current standard blade and the thickness value. As a result of the literature researches on the knife surface, it was decided that the structure to be applied will be a honeycomb structure. Because honeycomb geometry is the largest number of geometries that can be placed in an area in terms of its shape, and when the stress distribution is examined, its strengths in the x, y and z directions are very close to each other. It has been deemed necessary to make a mold in order to form a honeycomb structure on the surface of the knife and to produce the knife in series. Mold production was made for the printing of the products. The manufacturing flow determined for the designed bionic circular blade is given in Fig. 12.

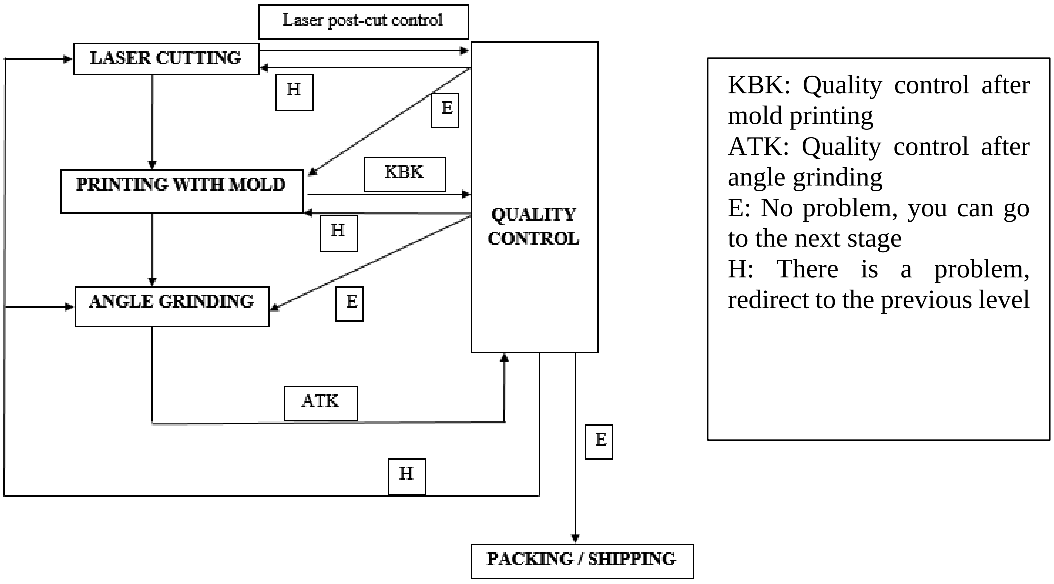

Figure 12. Production Flow of the Designed Bionic Circular Blade

The prepared mold was placed in the press in order to realize the printing. The product obtained after applying the specified load to the piece is given in Fig. 13.

Figure 13. The obtained part after printing in press

Mouth grinding of the product was carried out by applying angle grinding operation after printing in the press. During the use of the current standard blade, the cutting function cannot be performed due to blunting in the mouth and if the spare is not removed by the machine, the sharpening process is expected, and if it is redundant, the production is continued by replacing the sharpened or new blade. In order to eliminate this problem, it is aimed to create a design in which the bionic knife is designed, in which production is not stopped during a shift without blinding during use. If this system is used successfully, it will save 5-7% time in production. In Fig. 14, the bionic circular knife, which is sharpened and ready to use, is given.

Figure 14. Bionic circular knife with sharpening and ready to use

After the printing process of the part was completed in the press, grinding process was done on the mouth. When controlled with micro hardness, hardness differences were observed.

For the cutting edge of the bionic circular blade, a self-sharpening structure is considered during the study. In the construction of this structure, the permanent sharp feature of the mountain rat's tooth has been used. Due to the difference in hardness between the surface of the mountain rat's teeth, the teeth show the feature of staying sharp every time after cutting. By using this feature, the bionic circular knife cutter bend was made in an angle towards the bending direction. Here, due to the shrinkage in the lower part of the angle, the softening of the material is considered to occur due to shrinkage in the upper part of the angle.

3.5. Testing the performance of the bionic circular knife

The production flow for the current circular blade was examined and a new blade design was needed due to the problems experienced during this flow. A new production flow has been designed for the bionic circular blade.

The currently used material type and thickness parameter have been changed. A decision was made to make a mold so that the bionic circular blade can be produced with the changing production flow. And in order to make mass production of bionic circular knife, a mold was designed and the mold was produced.

Sample materials suitable for changing material type and thickness parameter were prepared and printed with mold. In order for the honeycomb structure to be at the specified depth, the load to be applied has been determined and an appropriate press research has been made to apply this load. As a result of the studies in the literature, it was decided to process the honeycomb tissue structure on the bionic circular knife. Necessary arrangements have been made for the mold to be printed in accordance with this structure. The mold and samples to be printed were prepared and the products were printed on the mold. Mouth sharpening process for the products that are pressed in the press was made in another manufacturing process. After the mouth sharpening of the bionic circular knife is done, it is put into the machine on the production line and trial is made.

The current standard circular blade is a blade that comes into contact with food. The blades are used in the production line, which operates in 3 shifts and makes approximately 100,000 cuts in one shift. Production is continued by removing the knife on the machine every 3-4 hours in a shift by replacing it with a new or sharpened knife. During this disassembly process, production stops and production time is lost. In order to eliminate this problem, a product design that does not require removal and installation is designed. The working principle of the knife is to make a slit on the stony areas coming from the cutting path and to clean the solid materials in the stony. The knives prepared for trial are mounted on the machine and the trial work is done on the line.

The working times obtained as a result of the experiments with the bionic circular knife are given in Table 3.

Table 3. Working times of bionic circular knife as a result of trial

Trial	Shift	Working time
1	Day	3 Hours
2	Night	7 Hours
3	Night	10 Hours

There may be some stone, metal or plastic materials that can mix between the feed during the feeding of the chicken. Chicken can eat these items without distinguishing them. The stony organ of the chicken undertakes the task of breaking and grinding the feed. In the first attempt, the bionic circular knife worked for 3 hours and the blade was damaged due to the fact that the solid materials coming out of the stony coincided with the 4 channels around the blade. After detecting that the canal areas of the bionic circular blade were damaged, the correction was made as follows. The duct size of the bionic circular blade was reduced and the width was narrowed and the blade was produced. As a result of this measure, the working time has increased to 7 hours. Although this time zone is a sufficient time period compared to the standard circular knife, it has been corrected again in order to prolong its working life. This correction was as follows. 4 channels around the bionic circular blade were canceled and the blade was pressed without channel. Then, a different type of channel was created with a different operation compared to the standard channel. It has been proven that the working life is extended in the next attempt.

After the splitting process on the stony is completed, the stony stones are removed from the solid materials in it. After this stage, disinfection is carried out on the stony free of solid materials. Thus, it is directed to the next process line to be cleaned from stony foreign materials and packaged.

As a working principle of the blade, it performs the function of slit on the stony. The cutting performance of the standard circular blade currently used on the line has been observed. It has been determined that the standard circular knife used in the present situation has the same performance values as the bionic knife in the splitting process on the stony. Slits with slits were examined with a standard circular blade. For the trial study, the slits on the stony areas were examined with the bionic circular knife attached. As a result of the comparison, it was seen that both blades provide the same slitting performance and even the bionic knife shows higher efficiency performance.

It is determined that the standard circular blade used in the current situation is used until there is a 6% decrease in the outer diameter value. As a result of the blunting experienced during the operation of the blade in the machine, the sharpening process is carried out by removing the blade from the machine to make sharpening to the cutting edge. During this process, production time is lost. As a result of testing the designed bionic circular blade by attaching it to the machine, it was determined that it was used without requiring sharpening for two shifts. It was observed that there was a 2% reduction in outer diameter at the end of the shift. This obtained value showed that the blade can be used up to the last used diameter of the standard circular blade currently used for 3 shifts without any problem with no hard material. During the operation of the blade, a wear caused by friction occurred. As a result of the 10-hour study, a 4.31-gram mass loss was observed in the blade. During a shift, 100,000 product cuts are made. It is assumed that the mass loss experienced is distributed equally over 100,000 products. It is assumed that 0.0000431 grams of powdered metal per stony cut contact the stony. There is a metal detector in certain parts of the line for the detection of metal parts that may break from the machine in such production lines. The amount of metal that the metal detector does not detect does not pose any problems for food. The metal detector detects the rate of metal in the product. Since it is disinfected before this part, the product is sufficiently purified. In the study, it has passed the metal detector test without any problem. Therefore, metal dusts resulting from wear are cleaned during the disinfection stage.

Stainless steel group material was used for the material of the bionic circular knife designed in this study. The chemical composition of the material used is given in section 3.4. In the Turkish food codex raw poultry meat and prepared poultry mixes communiqué, it was determined that any of the elements that should not touch the food in the contaminants section is not included in the designed bionic knife [10, 11]. It has been determined that the reduction in diameter during the operation of the bionic circular knife will not cause any negative effects on food.

4. Evaluation of experimental results

By producing the bionic circular knife designed, data was obtained during the operation of the knife on the production line. In this section, the data obtained during the operation of the standard circular blade and the bionic circular blade are compared in terms of blade life, cutting performance and production costs.

4.1. Evaluation of blade life

In this section, a comparison is made between the standard circular blade and the bionic circular blade designed considering the current problems. The annual use of the knife used in the current situation has been determined by examining the number of pieces used in previous years. By considering the time data obtained during the operation of the bionic circular knife, the number of products that can be used annually has been determined.

The material of the designed bionic circular blade was used differently from the material of the standard circular blade currently used. It has been observed that this change in the material positively affects the life of the product.

It has been determined as a result of the examinations that there are 100 uses per year from the standard circular knife used in the current situation. It has been observed that a disassembling operation is performed on the blades for sharpening every 3 hours during a shift. Thus, it was observed that the solid materials in the stony were changed at least 2 times in order to grind the knives in a shift, unless there is an opposite situation such as breakage in the blade. In some cases, the solid materials coming out of the stony cause great breaks in the standard circular blade and make them unusable. It has been determined that this situation causes loss in production time and increase in cost.

It has been observed that the blades blunting problem occurs during the shift in the standard circular blade and sharpening process is carried out in order to continue the production. In order to eliminate this time loss in the bionic circular knife to be made, a self-sharpening structure was considered in the design of the cutting mouth part of the bionic circular knife by taking the incisors of the mountain mouse. Thus, as the initial target, the bionic circular blade is intended to be used for one shift. It has been observed that the designed bionic circular blade works for 10 hours (three shifts) without any problems as a result of the trials. Based on this result, trial studies on blade performance continue.

4.2. Evaluation of cutting performance

Data on cutting performance were obtained during the operation of the standard blade on the production line. The bionic knife performs slotting on the stones from the previous production line. The slits cut on the stony are opened at a certain depth. In case of opening the slit lower than this determined depth value, it cannot be purified from the solid materials in the stony. Stones in this case are separated from the line as defective products.

When the cutting performance of the standard circular knife working in the current situation is evaluated, the results are as follows. The blade is replaced every 3 hours during the 8-hour shift due to blunting. The cutting performance at the beginning of the shift and the cutting performance 3 hours after the start of production vary. It has been observed that the cutting performance of the standard circular blade is reduced 3 hours after the start of cutting. During working on the standard circular blade, blunting occurs in the cutting edge. Due to the dullness experienced in the blade, the production was continued by removing the blade from the machine and replacing it with a new or sharpened standard circular blade.

The bionic circular knife designed was mounted on the machine and trial work was carried out. As a result of the trial studies carried out with the knife, data on cutting performance were obtained. Three of the results obtained as a result of the trial studies conducted within the scope of the thesis study have been given and evaluated within the scope of the study. One of the test results obtained as a result of the bionic circular knife working on the machine is 3 hours of operation. The bionic circular blade worked for 3 hours, showing the desired cutting performance values. As a result of the presence of solid materials in the stony after 3 hours, ruptures occurred in the cutting edge of the bionic circular blade. Due to this problem, the blade was removed from the machine. A new bionic circular knife was installed and trial work continued. The bionic circular knife installed in the next trial carried out a slit on the stony at the cutting performance values determined for 7 hours. As a result of the tears in the mouth at the end of 7 hours, the bionic circular knife was removed from the machine and a new bionic circular knife was replaced and trial studies continued. Another trial result evaluated within the scope of the study; After the bionic circular blade is installed on the machine, it is the result of the trial that it worked without any change in cutting performance for two shifts. No difference was observed between the original slit on the stony and the slit on the stony after 10 hours. During the 10-hour operation, the machine was not removed from the machine for sharpening. No sharpening was performed during the operation of the bionic circular blade. During this process, the knife performs self-sharpening thanks to its mouth structure designed as a sample of the mouse tooth as it works. Thus, the loss of time during the disassembly and assembly processes has been turned into production time. When the time lost during disassembly operations is converted to production time, it increases 5-7% in production. Since the sharpening process of the blade is eliminated, the labor, machinery, equipment expenses that have arisen for the sharpening process are also eliminated.

4.3. Evaluation of production cost

In this section, the costs incurred during the production of the standard circular knife currently used are determined. These costs were compared with the costs incurred during the production of the designed bionic circular blade.

In Fig. 15, the production costs during the production of the standard circular knife are given. Costs incurred during manufacturing; material, heat treatment and mold due to heat treatment appear as labor cost, operation cost.

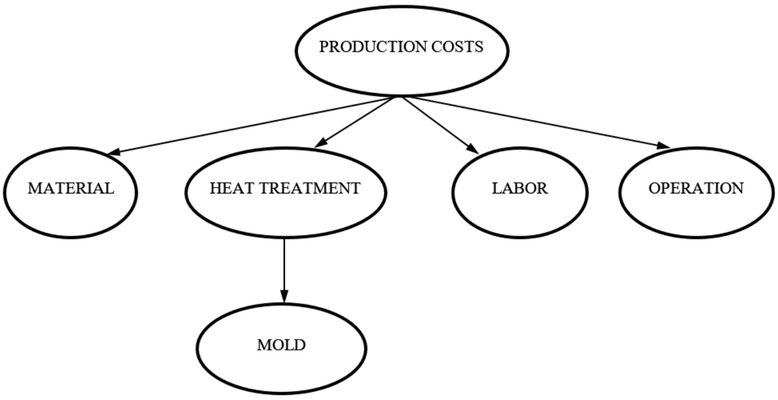

Figure 15. Classification of production costs

When evaluated as material cost, the amount of material used for the standard circular blade is 1.4034 (EN X46Cr13 and AISI 420) material with an outer diameter of 175.00mm and a thickness parameter of 2.50mm. For the bionic circular blade, material parameters of 1.4301 (EN X5CrNi18-10 and AISI 304) material thickness 0.60mm were used. 76% less material was used in the volume of material used for one product. Considering the cost of the material, a decrease in this ratio was observed. In summary, the advantages of the developed bionic blade are tabulated in Table 3 comparing to the standard blade.

Table 3. Comparison between standard blade and bionic blade [2]

Comparison parameters	Standard blade	Bionic blade
Production process stages	7 steps	4 steps
Production cost	-	40% decreased
Production capacity	-	5-7% increased
Blade thickness	2.5 mm	0,6 mm
Service life	same	same
Knife sharpening number	2-3 times in the shift	none
Sales cost	-	84% decreased
Production time	-	40% decreased

5. Conclusions

In the present study, biomimetics were used in all design stages of the designed bionic circular blade. Steps followed for the design of the bionic circular blade; bionic circular blade design, mold design and mold production for blade production, printing of prepared samples in mold, testing of produced bionic circular blade. Fig. 16, shows the general framework of the present study.

Figure 16. General structure of the study

Finite element method is used for optimization. The analyzes were repeated theoretically until the best result was obtained. Samples were produced using the best results obtained and then tests were carried out. Apart from this, optimization technique was not used.

The main results obtained in the research are as follows:

a) The heat treatment step was removed from the manufacturing flow of the bionic circular blade. The removal of this manufacturing stage, molding cost, the cost created by the mold material taken for molding the products and the heat treatment cost are eliminated. Depending on the heat treatment stage, thickness and hole grinding steps were also removed from the product's manufacturing flow. Thus, the 7-stage manufacturing flow followed for the standard circular knife has been reduced to 4 stages for the bionic circular knife.

b) Due to the removal of heat treatment processes, the production time of the product is decreased by 40%.

c) For the currently used product, the material type and thickness size are used differently than the bionic circular blade. 2.50mm thickness size used in standard circular blade, 0.60mm thickness in bionic circular blade. Thus, up to 76% material was saved. In terms of material cost, a cost reduction of about 60% was observed.

d) The bionic circular blade is designed to operate without sharpening. For this reason, blindness problems currently experienced in the designed blade are not experienced. It has been observed that the blade has a positive effect on the production amount since the disassembly and assembly problems are eliminated.

Research continues to increase the 10-hour application time achieved without the need for sharpening.

References

[1] M. Genç, Nature, science and biomimetic science. Ankara: Hacettepe University, Turkey 2013.

[2] O. Bekci. (2018). Increasing the Sharpness Performance of Stainless Blades by Cold Deformation Method as an Example of Biological Functions, MSc Thesis, Sakarya University, Turkey

[3] M. Nosonovsky and P. K. Rohatgi, Biomimetics in materials science. Springer-Verlag, New York, 2012. [4] R. Bonser, "Patented biologically-inspired tecnological innovations: a twent year view", *Journal of Bionic Engineering*, vol. 3, no.1, p. 39-41, 2006.

[4] R. Bonser, "Patented biologically-inspired tecnological innovations: a twent year view", *Journal of Bionic Engineering*, vol. 3, no.1, p. 39-41, 2006.

[5] Z. Xia, Biomimetic Principles and Design of Advanced Engineering Materials, Texas, Wiley, 2016.

[6] W. D. Callister and D. G. Rethwisch, Applications and Processing of Metal Alloys. in W. D. Callister, & D. G. Rethwisch, Materials Science and Engineering, London: Wiley, 2010.

[7] Metal and Welding Technologies, Metal expert: http://www.metaluzmani.com/celiklerde-kullanilan-standartlar/, August 22, 2018.

[8] C. Wegst, Key to Steel, Verlag, Marbach, Germany, 2019.

[9] G. E. Dieter, Fundamentals of Metalworking, in Mechanical Metallurgy, McGraw-Hill, New York, 1988.

[10] Ministry of Agriculture and Rural Affairs, Turkish food codex notification of raw poultry meat and prepared poultry meat mixtures (Publ. no: 2006/29). Ankara: Official Newspaper, 2006.

[11] Ministry of Agriculture and Rural Affairs, Turkish food codex contaminants regulation. Ankara: Official Newspaper, 2011.