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PART A: ENGINEERING AND INNOVATION

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Finite Element Analysis to Predict Thrust Force and Torque in Drilling of Aged and Annealed Inconel 718

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Thrust force,
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Abstract

In this study, drilling of two kinds of Inconel 718 superalloys (aged and annealed) were simulated with FEM based Deform 3D V.11 software, and the effects of feed rate and cutting speed on thrust force and drilling torque have been investigated. A 5 mm diameter uncoated carbide twist drill with a web thickness of 0.75 mm was modelled, and drilling operations were simulated for two feed rates (0.05 and 0.1 mm/rev) and two cutting speeds (10 and 20 m/min). The workpieces were modelled by using Johnson-Cook (J-C) material model whose parameters acquired from the published literature. Thrust forces and drilling torques of aged Inconel 718 were found to be considerably larger than that of annealed Inconel 718 under the same cutting conditions.

1. INTRODUCTION

Drilling process is one of the most significant machining processes that constitute about 22% of all machining processes in terms of the number of operations. It is often performed as one of the last operations in production of parts. On the other hand, drilling process is more complex than other machining operations, i.e. turning and milling, in terms of the kinematics and dynamics of the process, the process control, the chip removal and cutting heat dissipation. The drill tool properties and the process parameters should be properly determined by considering the specific drilling requirements and workpiece material. In this regard, drilling, and naturally other metal cutting operations, have been studied extensively in the published literature. Although experimental-empirical method for investigation of right parameters for metal cutting operations is often the main reference in the industry, it is valid for the ranges of the experiments conducted, and furthermore, it is costly and time consuming. Therefore, considerable progresses have been seen in the development of other industry-driven predictive models for machining operations in the last few decades. They may be categorized as analytical, numerical, Artificial intelligence (AI) based, and hybrid modelling techniques. Among them, numerical methods implemented to commercial codes, providing opportunities to connect to industry-relevant parameters, have been extensively used by the researchers [1-3].

Inconel 718 is a nickel-chromium based high strength superalloy. It is resistant to the variety of corrosive conditions, pitting and crevice corrosion. It provides outstanding mechanical properties like high tensile, fatigue and creep-rupture strength at elevated temperatures. It is used at cryogenic (-252 ^{0}C) to high (704 ^{0}C) temperatures. The alloy is preferred for use in aeronautics and land based gas turbines, marine engineering, nuclear power plants, etc. [4,5].

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Inconel 718, like many other superalloys, is known as difficult-to-cut alloy. Work hardening, high temperature strength, poor thermal conductivity, abrasive and adhesive mechanism due to high amount of carbides in the alloy, adhesive tendency of the nickel, high heat generation are the prevalent reasons for the difficulty in machining Inconel 718 [6,7].

Although numerous research works have been carried out on turning and milling of Inconel 718, research on drilling of Inconel 718 is relatively limited in the published literature [7,8]. Likewise, less number of studies on drilling of different superalloys can be found in the literature.

Since cutting forces affect cutting temperatures, tool wear, surface integrity, power consumption, etc. considerably, they have been investigated substantially. As it is well known that the feed rate and the cutting speed are the primary machining parameters that determine the cutting forces. In the studies investigating the effects of cutting conditions on cutting forces, apart from dry cutting, various cooling methods have been also used to improve machinability. A few researches on the subject are given below.

Uçak et al. analysed experimentally and numerically the drilling operation on annealed Inconel 718 at dry cutting conditions, to investigate thrust force, torque and temperature [8]. They used Deform 2D and 3D to simulate the drilling operation and observed a good agreement between the numerical and experimental results.

Jian and Rongdi studied the drilling of Inconel 718 in terms of drilling deformation and drilling forces distribution. They obtained the drilling chip specimens by using self-made drilling quick-stop device. An empirical formula of shear angle was derived from the results of dry drilling tests. Thrust and torque values according to various cutting speeds and feed rates were recorded, and the ratio of thrust and torque on the lead cutting edge were determined. They compared all the results of Inconel 718 with that of AISI 1045 steel [9].

Rahim and Sasahara investigated experimentally the effect of high speed drilling under minimum quantity of lubrication conditions on drilling performance and surface integrity of Inconel 718. It was observed that, the thrust force and torque values decreased linearly with increasing cutting speed, and the values increased significantly with increasing feed rate. The cutting speed also influenced the distribution of the surface roughness significantly. Moreover, findings about tool wear, workpiece temperature, surface roughness and hardness variations beneath the machined surface were noted [7].

Nagaraj et al. simulated drilling operation of Nimonic C-263 superalloy to investigate the thrust force, temperature generation, effective stress and strain by varying the spindle speed, feed rate and point angle. They compared the simulated thrust force and drill bit cutting edge temperature with the experimental results and observed 10% of error [10].

Using a 3D FEM, Parida studied drilling operation of Ti-6Al-4V, to simulate thrust force, torque, effective stress, effective strain, drill bit temperature, surface roughness and circularity by changing cutting speed and feed rates. Among the simulated results, Parida compared thrust, torque and circularity with the experimental results and observed a good agreement with few errors [11].

As known, heat treatment processes are applied to metals widely in order to change the physical and mechanical properties in a desirable way. Objectives of heat treatment process are; to increase strength, hardness, ductility, toughness, etc., and to improve formability, machinability, etc., for engineering applications of metals. Accordingly, differently heat treated, namely aged and annealed types of Nickel based superalloy Inconel 718 exhibit different physical and mechanical, especially strength and thermo-visco plastic, properties. Machinability properties of these materials naturally vary considerably. In this respect, the aim of this paper is to investigate numerically the effects of cutting conditions (feed rate and cutting speed) on the machining performance (thrust force and drilling torque), in drilling of aged and annealed types of Inconel 718.

2. METHODS

In this paper, drilling simulations were performed using SFTC DEFORM 3D V.11. In the simulations, a 5 mm diameter uncoated carbide twist drill with a web thickness of 0.75 mm was modelled to drill two different types of Inconel 718 (aged and annealed) superalloy. Drilling operations were simulated at two feed rates (0.05, 0.1 mm/rev) and two cutting speeds (10, 20 m/min). The limited material chemical composition for Inconel 718 is given in Table 1.

Table 1. *Limiting chemical compositions of Inconel 718* [4]

ELEMENTS	Min %	Max %
Nickel + Cobalt	50.00	55.00
Chromium	17.00	21.0
Iron	Balanced	
Niobium + Tantalum	4.75	5.50
Molybdenum	2.80	3.30
Titanium	0.65	1.15
Aluminum	0.20	0.80
Cobalt	....	1.00
Carbon	....	0.08
Manganese	....	0.35
Silicon	....	0.35
Phosphorus	....	0.015
Sulfur	....	0.015
Boron	....	0.006
Copper	....	0.30

2.1. Twist Drill Model

For drilling of Inconel 718 at dry cutting conditions, using of uncoated carbide tools with lower feed rates was recommended for better hole quality [12]. A 3D twist drill model was created and meshed in the Deform 3D software and assumed to be rigid, shown in Figure 1. 15% Cobalt uncoated carbide was selected as tool material. Geometric parameters are as follows: drill diameter of 5 mm, web thickness of 0.75 mm, helix angle of 30^0 and point angle of 140^0.

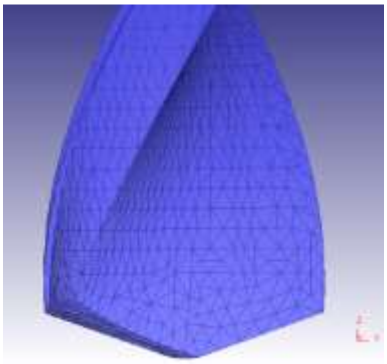

Figure 1. *Meshed twist drill model*

Twist drill mesh properties and other related assumptions made in the FEM analysis are given in Table 2.

Table 2. *Twist drill mesh properties*

Assumptions	Values
Tool Material	Carbide %15 cobalt
Mesh Size ratio	4
Element type	Tetrahedral
Mesh type	Fine Mesh
Surface polygons	4,296
Nodes	2,150 nodes
Relative mesh type	32,000

2.2. Workpiece Model

The workpiece was modelled as a disc having a diameter of 7 mm and a height of 2.5 mm. To start the cutting process immediately at full load, a pre-machined conical hole was generated on the workpiece to a specific depth. As a function of the Deform 3D, the conical hole is created exactly from the imprint of drill bit as shown in Figure 2.

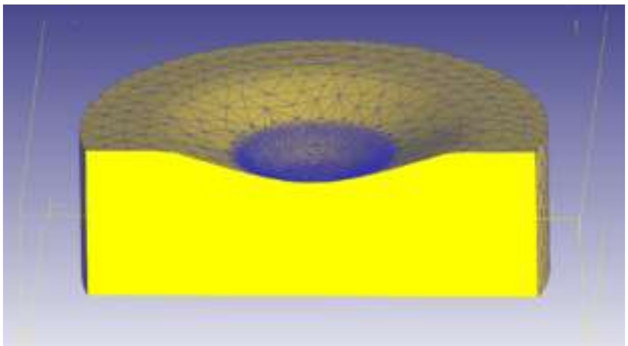

Figure 2. *Meshed workpiece model with pre-machined conical hole*

By following this method, the simulation time is dramatically reduced, because the space between the cutting edges of the twist drill and the workpiece is minimized so that the machining process starts immediately at full load [13]. For achieving accepted results of thrust force and torque, the conical part of the twist drill must be completely entered into the workpiece. So that preparing a pre-machined hole decreases the computation time considerably to reach at this point. In each case, the depth of the pre-machined conical hole measured on the axis is adjusted to be a bit smaller than the height of the conical end of the drill bit, so that after a specific number of rotation which is related to the feed rate, drill's conical end completely enters into the workpiece.

The workpiece has been modelled as a plastic deformable with a mesh size of 80,000. For the simulations, different mesh sizes were tried from 35 thousand to 135 thousand. Although no significant differences were observed in thrust force and torque results, the lower mesh sizes led to bad chip geometry, the higher mesh sizes increased the computation time and caused extremely large amount of result files in hard disc. So 80 thousand mesh size was used as the optimum mesh size for the simulations in terms of good chip geometry and reasonable computation time. Workpiece mesh properties and other related assumptions made in the FEM analysis are given in Table 3.

Table 3. *Workpiece mesh properties and other related assumptions in the FEM analysis*

Assumptions	Values
Mesh size	80,000
Mesh Size ratio	10
Number of nodes	22,500
Work material type	Plastic
Surface polygons	19,800
Shear friction factor	0.6
Heat transfer coefficient	45 N/Sec/mm/C
Coolant	not used (Air assumed)
Environment Temperature	20°C
Convection Coefficient	0.02 (Air)
Number of Simulation steps	1000
Step increment to save	10

The thermal properties of the Inconel 718 were taken from the Deform's material database.

A realistic material model describing the material flow curves adequately should be used for an accurate finite element analysis of a machining operation. Semi-empirical Johnson-Cook constitutive model is widely used material model due to its simplicity and availability of the parameters for significant materials. Thus, in this study, J-C model given below was employed [14, 15].

$$\bar{\sigma} = [A + B\bar{\varepsilon}^n]\left[1 + C\ln\left(\frac{\dot{\bar{\varepsilon}}}{\dot{\bar{\varepsilon}}_0}\right)\right]\left[1 - \left(\frac{T - T_{room}}{T_m - T_{room}}\right)^m\right]$$

where $\bar{\sigma}$ is the equivalent stress (MPa), $\bar{\varepsilon}$ is the equivalent plastic strain, $\dot{\bar{\varepsilon}}$ is the equivalent plastic strain rate (s^{-1}), $\dot{\bar{\varepsilon}}_0$ is the reference equivalent plastic strain rate (s^{-1}), T is the temperature (°C), T_m is the material melting temperature (1500°C - Deform value) and T_{room} is the room temperature (20°C - Deform value). J-C model constants are *A*, the initial yield strength of the material at room temperature, *B*, the strain hardening coefficient, *C*, the strain rate hardening coefficient, *n*, the strain hardening exponent, and *m*, the thermal softening exponent. J-C model constants are determined by fitting the data acquired from material tests carried out at several strain rates and temperatures. In the J-C model, the expression in the first set of brackets is the strain hardening effect. The expressions in the second and third set of brackets are strain rate hardening and thermal softening effects, relatively.

The J-C model parameters used in this study for both aged and annealed Inconel 718 were taken from the study of Ozel et al. [15], and are shown in Table 4. They have referred the J-C parameters for aged Inconel 718 to Lorentzon et al. (2009) [16], and referred the J-C parameters for annealed Inconel 718 to Uhlmann et al. (2007) [17]. The yield strength values of aged and annealed Inconel 718 are 1241 MPa and 450 Mpa respectively.

Table 4. *Johnson-Cook model parameters for Inconel 718* [15]

Heat Treatment	A (MPa)	B (MPa)	C (-)	n (-)	m (-)	$\dot{\bar{\varepsilon}}_0$ (s^{-1})
Aged	1241	622	0.0134	0.6522	1.3	1
Annealed	450	1700	0.017	0.65	1.3	0.001

2.3. Simulations

According to the simulation plan shown in Table 5, four drilling simulations were performed on Deform-3D software, for each of aged and annealed Inconel 718 superalloy.

Table 5. *Simulation plan for drilling of aged and annealed Inconel 718*

No. of operations	Cutting speed (m/min)	Feed rate (mm/rev)
1	10	0.05
2	10	0.1
3	20	0.05
4	20	0.1

The simulations were performed on two different computers, one having Core i7 processor with an 8 GB of RAM and the other having Core i5 processor with a 6 GB of RAM. The computation time on each computer for each simulation was approximately 10 to 12 hours to complete one single revolution of the twist drill, which was sufficient in most cases to get the mean steady-state values of thrust forces and torques.

3. RESULTS AND DISCUSSION

In drilling operation, after entry phase, the steady-state phase is reached when the fluctuations and the variations of thrust forces/torques take place almost about an approximate value (typical entry and steady-state phases of torques with fluctuations when drilling Inconel 718 can indeed be identified from Figure 3). The mean steady-state value is determined by transferring the data in the steady-state interval to MS Excel and calculating the mean value. All drilling simulation results for aged and annealed Inconel 718 are given in Table 6.

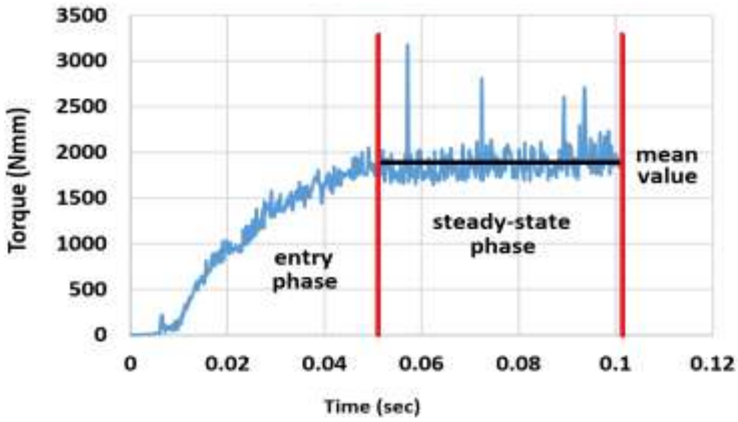

Figure 3. *Typical entry and steady-state phase of torques*

Table 6. *Drilling simulation results for aged and annealed Inconel 718*

No. of operations	Cutting speed (m/min)	Feed rate (mm/rev)	Thrust force (N)		Torque (Nmm)	
			Aged	Annealed	Aged	Annealed
1	10	0.05	742.17	228.93	1888.21	660.61
2	10	0.1	816.49	294.01	3684.34	1395.78
3	20	0.05	599.78	219.75	1345.11	561.50
4	20	0.1	666.15	269.81	3280.43	1043.75

In drilling of both aged and annealed Inconel 718, the thrust force increases with increase in the feed rates, for both of the cutting speeds, see Figure 4. This result agrees with the experimental [7, 10, 11, 18, 19] and simulated results [10, 11, 18] found in the literature. When the cutting speed variation is considered, a decrease is observed in thrust force values of both aged and annealed Inconel 718 with increase in the cutting speeds, see Figure 5. This result agrees with the experimental [7, 11, 19, 20] and simulated results [11] found in the literature.

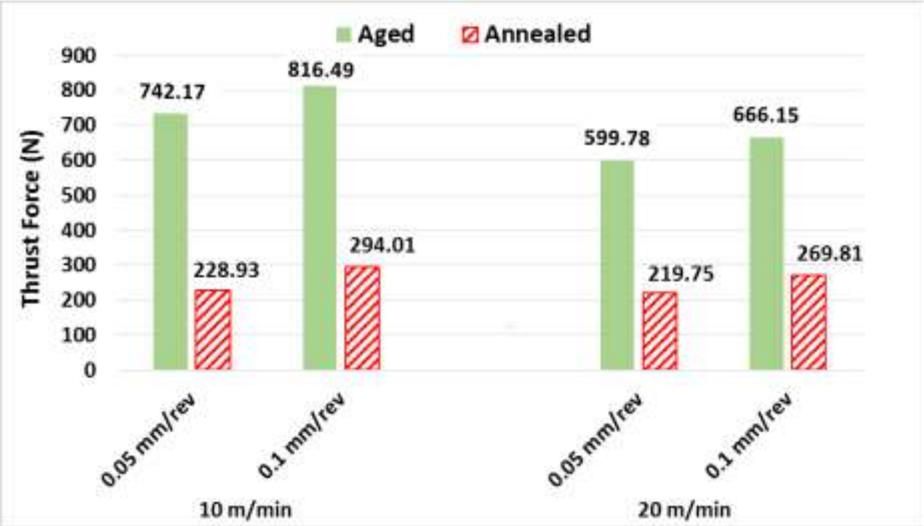

Figure 4. *Thrust force results for drilling of aged and annealed Inconel 718 with varying feed rates at each cutting speed.*

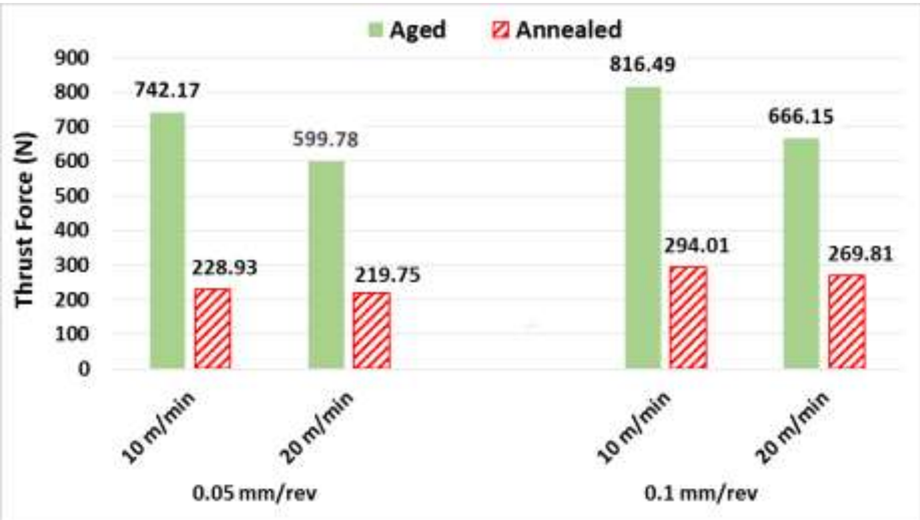

Figure 5. *Thrust force results for drilling of aged and annealed Inconel 718 with varying cutting speeds at each feed rate.*

In drilling of both aged and annealed Inconel 718, the drilling torque increases with increase in the feed rates, for both of the cutting speeds, see Figure 6. This result agrees with the experimental [7, 11, 19] and simulated results [11] found in the literature. When the cutting speed variation is considered, there is a decrease in torque values of both aged and annealed Inconel 718 with increase in the cutting speeds, see Figure 7. This result agrees with the experimental [7, 11, 19, 20] and simulated results [11] found in the literature.

As pointed out above, in drilling of both aged and annealed Inconel 718, thrust force and torque values increase with increasing feed rates. This can be explained by cutting mechanics theory; as the feed rate increases, instantaneous cutting area increases leading to larger cutting forces, thereby thrust force, and torque [21]. On the other hand, thrust force and torque values of both aged and annealed Inconel 718 decrease with increasing cutting speeds. This behaviour can be attributed to reduction of strength due to thermal softening effect within the considered cutting speed range for dry cutting conditions [22].

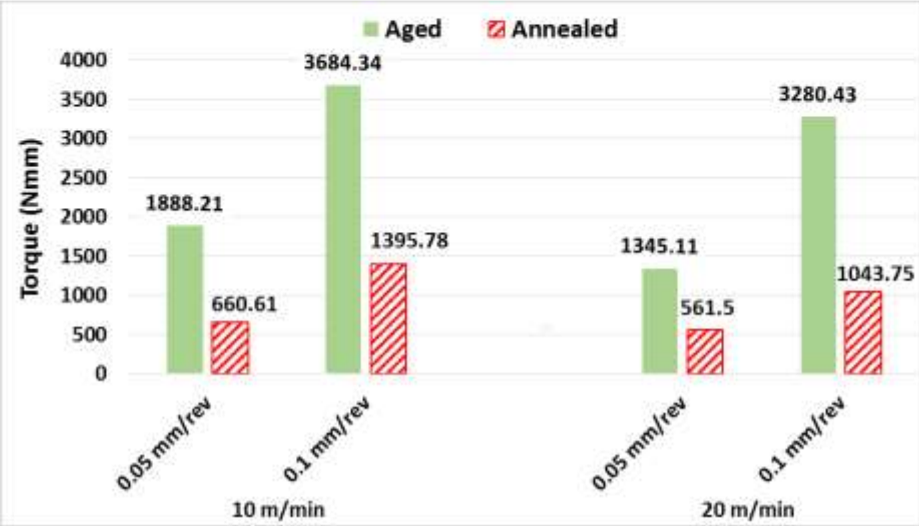

Figure 6. *Torque results for drilling of aged and annealed Inconel 718 with varying feed rates at each cutting speed.*

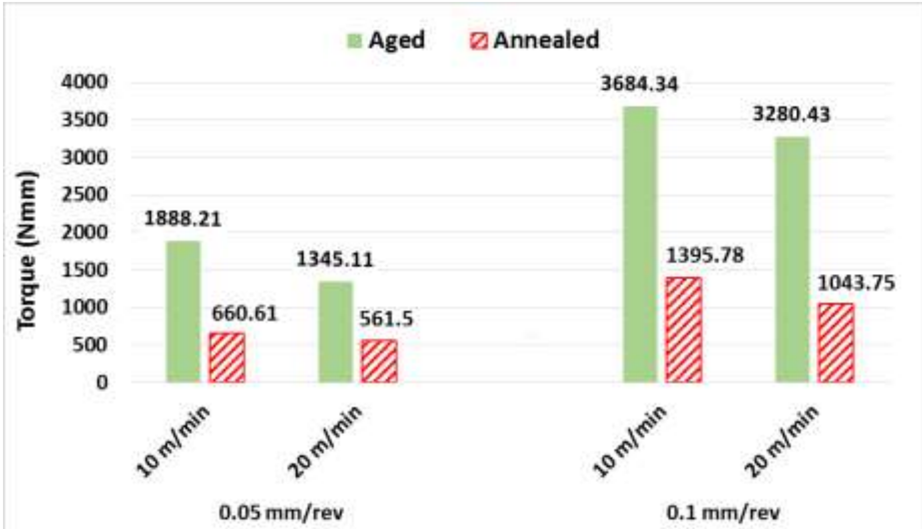

Figure 7. *Torque results for drilling of aged and annealed Inconel 718 with varying cutting speeds at each feed rate.*

4. CONCLUSIONS

In this paper, the effects of feed rate and cutting speed were examined numerically in drilling of both aged and annealed Inconel 718 superalloys.

The following conclusions can be drawn from this study:

- Both materials have shown similar thrust force and drilling torque trends depending on feed rates and cutting speeds: the thrust forces and drilling torques for both materials increase with increasing feed rates and decrease with increasing cutting speeds.

- Thrust force and drilling torque values of aged Inconel 718 were remarkably larger than that of annealed Inconel 718, in all cases. This is already an expected trend because aged Inconel 718 has higher strength than does annealed Inconel 718 in plastic deformation.
- The smallest thrust forces and drilling torques for both materials were obtained at minimum feed rate (0.05 mm/rev) and at maximum cutting speed (20 m/min). On the other hand, the largest thrust forces and drilling torques for both materials were obtained at maximum feed rate (0.1 mm/rev) and at minimum cutting speed (10 m/min).
- Simulation results could be compared with experimental ones quantitatively for validation.

CONFLICT OF INTEREST

The authors declares that, there is no conflict of interest regarding the publication of this paper.

REFERENCES

[1] Tonshoff, H.K., Spintig, W., Konig, W., Neises, A., “Machining of holes developments in drilling technology”, *Annals of the CIRP*, 43 (2): 551-561 – (1994).

[2] Arrazola, P.J., Özel, T., Umbrello, D., Davies, M., Jawahir, I.S. “Recent advances in modelling of metal machining processes”, *CIRP Annals – Manufacturing Technology*, 62: 695–718, (2013).

[3] Rodríguez, J. M., Carbonell, J. M., Jonsén, P., “Numerical methods for the modelling of chip formation”, *Archives of Computational Methods in Engineering*, 27:387–412, (2020).

[4] Internet, https://www.americanspecialmetals.com/inconelalloy718.html, last visit, 30.03.2020.

[5] Internet, https://super-metals.com/wp-content/uploads/2015/03/Inconel-718.pdf, last visit, 30.03.2020.

[6] Beer, N., Özkaya, E., Biermann, D., ‘‘Drilling of Inconel 718 with geometry-modified twist drills", Institute of Machining Technology, Dortmund, Germany, *Procedia CIRP* 24, 49 – 55, (2014).

[7] Abd. Rahim, E., Sasahara, H., “Application of minimum quantity lubrication when drilling Nickel-based superalloy at high cutting speed”, *Key Engineering Materials*, Vols. 407-408, pp 612-615 (2009).

[8] Uçak, N., Çiçek, A., Oezkaya, E., Aslantas, K., ‘‘Finite element simulations of cutting force, torque, and temperature in drilling of Inconel 718’’, *Procedia CIRP* 82, 47–52, (2019).

[9] Jian, Wu., Rongdi, H., “Research on drilling process of Nickel-based super-alloy”, *Applied Mechanics and Materials*, 33: 373–377, (2010).

[10] Nagaraj, M., John A., Kumar, P., Ezilarasan, C., Betala, R. ‘‘Finite Element Modeling in drilling of Nimonic C-263 alloy using Deform-3D’’, *Computer Modeling in Engineering & Sciences*, (2019).

[11] Parida, A.K., ‘‘Simulation and experimental investigation of drilling of Ti-6Al-4V alloy’’, *International Journal of Lightweight Materials and Manufacture*, 1, 197-205, (2018).

[12] Kıvak, T., Habalı , K., Seker, U., “The effect of cutting parameters on the hole quality and tool wear during the drilling of Inconel 718”, *Gazi University Journal of Science*, 25(2):533-540 (2012).

[13] Oezkaya E., Biermann, D., ‘‘A new reverse engineering method to combine FEM and CFD simulation three-dimensional insight into the chipping zone during the drilling of Inconel 718 with internal cooling’’, DOI:10.1080/10910344.2017.1415933, (2018).

[14] Johnson, G. R., Cook, W. H. “A constitutive model and data for metals subjected to large strains, high strain rates and high temperatures”, *Proceedings of the 7th Int. Symposium on Ballistics*, The Hague, The Netherlands, 541–547, (1983).

[15] Ozel, T., Llanos, I., Soriano J., and Arrazola, P.-J ‘‘3D finite element modelling of chip formation process for machining Inconel 718: comparison of FE software predictions’’, *Machining science and technology journal: An International Journal*, 15:1, 21-46, (2011).

[16] Lorentzon, J., Jarvstrat, N., Josefson, B.L., “Modelling of chip formation of alloy 718”, *Journal of Materials Processing Technology*, 209: 4645–4653, (2009).

[17] Uhlmann, E., Graf von der Schulenburg, M., Zettier, R., “Finite element modeling and cutting simulation of Inconel 718”, *Annals of the CIRP*, 56(1): 61–64, (2007).

[18] Strenkowski, J.S., Hsieh, C.C., Shih, A.J. “An analytical finite element technique for predicting thrust force and torque in drilling”, *International Journal of Machine Tools & Manufacture,* 44 1413–1421, (2004).

[19] Cuesta, M., Aristimuño, P., Garay, A., Arrazola P:J., “Heat transferred to the workpiece based on temperature measurements by IR technique in dry and lubricated drilling of Inconel 718 ”, *Applied Thermal Engineering*, 104: 309–318, (2016).

[20] Ema, S., “Effects of Twist Drill Point Geometry on Torque and Thrust”, *Sci. Rep. Fac. Educ. Gifu Univ.* (Nat. Sci.), 36: 165-174 (2012).

[21] Wang, J., Zhang, Q., “A study of high-performance plane rake faced twist drills. Part I: Geometrical analysis and experimental investigation”, *International Journal of Machine Tools & Manufacture*, 48: 1276– 1285, (2008).

[22] Sun, S., Brandt, M., Dargusch, M. S, “Characteristics of cutting forces and chip formation in machining of titanium alloys”, *International Journal of Machine Tools & Manufacture*, 49: 561–568, (2009).

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PART A: ENGINEERING AND INNOVATION

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Aerodynamic Wing Design with Biomimetic Approach and a Practice

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Research Article

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Abstract

Since the industrial revolution, the use of energy has become indispensable in our lives. Besides the increasing world population increases the need for energy, our need for petroleum-derived fuels, which are mostly obtained from underground sources in transportation vehicles, has increased. Limited, expensive, non-recyclable and insensitive to the environment, these fuels harm humanity for various reasons. Nowadays, besides the efforts to find alternative fuels for these fuels, the ways of using these fuels in the most economical way are being investigated. One branch of this research and development is aerodynamic design. In this study, in vehicle design, aerodynamic rim wing design is discussed. The aerodynamic structure of the wings minimized the swept air resistance. Thus, energy saving and wheel surface quality is improved.

1. INTRODUCTION

The Industrial Revolution is a major and radical change in the production structure and economy that has been achieved through the use of new power sources such as steam and mechanization. It is also referred to as Industrial Reform. Started in England in the second half of the 18th century [1].

In the early stages of the industrial revolution, steam-powered machines and vehicles (trains, ships, etc.) emerged. Later, electric, gasoline machines and vehicles began to be used. When energy is obtained from fossil fuels, combustion products (gases such as CO_2, NOx and SO_2) are dispersed in the atmosphere as flue gas. The flue gases also contain fly ash and hydrocarbons. Toxic metals such as nickel, cadmium, lead, arsenic are other substances that are thrown into the atmosphere as a result of burning of fossil fuels. CO_2 plays an active role in greenhouse effect formation. The increasing amount of CO_2 causes the temperature of the earth to rise, which leads to deterioration of the climate balance. SO_2 and NOx, combined with water vapor in the atmosphere, mainly lead to acid rain, which leads to deterioration of the ecological balance of the world. All fossil fuel residues cause air pollution that affects many of our cities during the winter months. Forests, agricultural lands and similar natural resources cause destruction [2].

As can be seen in Table 1, fossil fuels have been increasingly used since the industrial revolution. In These fossil fuels, the highest increase was seen in petroleum and its derivatives. With recent studies, it is still the most used energy source in the world, even if the rate of increase has declined. Table 2 envisages the use of energy sources that we will consume from 1990 to 2040. According to this study, fossil fuels are still at the peak. This is proof that savings in fossil fuel use need to be further increased.

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Table 1. *Global fossil carbon emissions graph [3]*

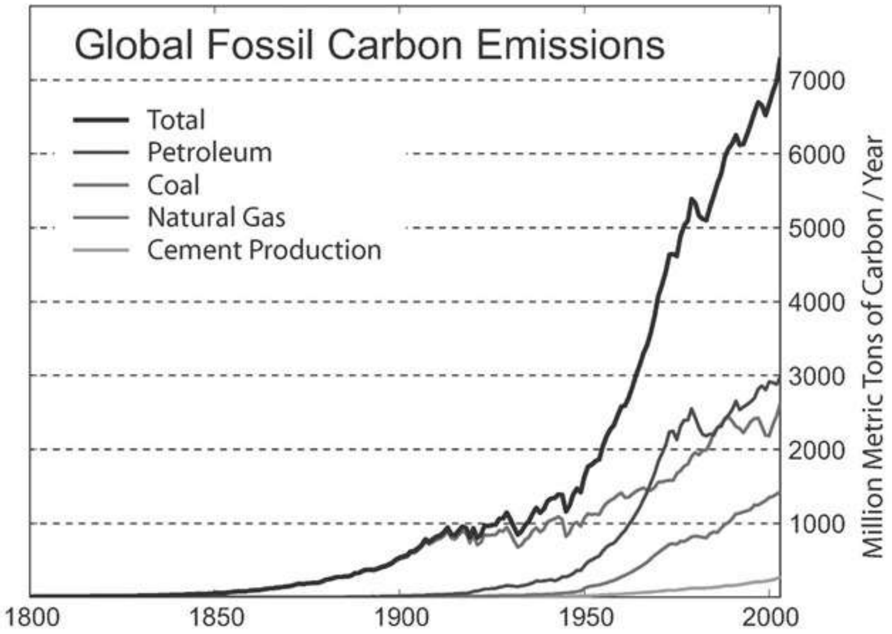
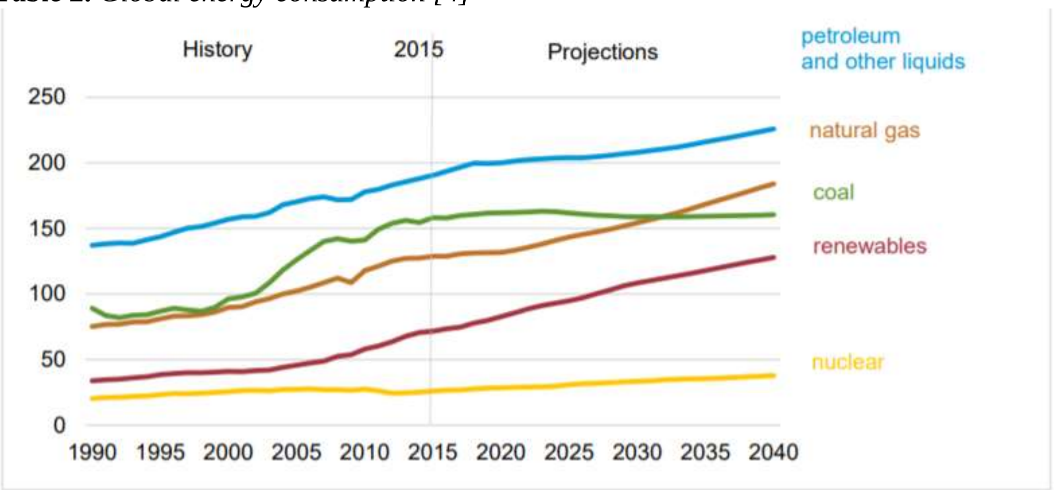


Table 2. *Global energy consumption [4]*



2. BIOMIMETICS

Developing vehicle designs with the invention of transportation vehicles began to give importance to aerodynamic structure. Many of today's designs have been made by adapting to the design thanks to the research of nature and alive. This branch of study is called Biomimetic.

Today, birds, fish inspired by aircraft, aircraft wings, wind turbine wings, cars and different types of designs are made. In our study, we will try to design the rim wing with these observations.

3. WING DESIGN

Besides there are rims of different structures as visual, these rims may be used for different purposes. One of them, in order to save fuel against wind resistance, it is desirable to optimize aerodynamics in vehicles. For this purpose, the rim design affects the aerodynamic structure. The wheel consists of body and wings. In this area, the rim design affects the aerodynamic structure to a small extent. The rim body is connected to the axles and the rim blades are connected to the tire. Since the wheel rotates with the body axis, there is no volume of air swept by the body. However, because of the gap between the rim blades, there is air inlet and outlet and this air forms resistance to the blades in motion. This resistance can be minimized by a suitable blade design. At the same time, the heat between the lining and the brake disc can be reduced with the imported air at a suitable angle. Thus brake performance can improve. In addition to being a uniform design, these blades can also be movable. During braking, the blades can be automatically angled and adjusted to sweep the air in and braking performance can be improved. Such studies can be increased and optimized. In this study, it is aimed to minimize the resistance forces acting on the aerodynamic structure and caused by the rim only.

In the study, commonly the most used in the market 5-wing model was selected as the number of rim wings. We were inspired by bird wings as wing structure and raindrop having the most perfect structure as wing cross section structure. Raindrop in Wing Design; Minimum Friction, Maximum Acceleration, Maximum Energy Saving, Minimum Energy Consumption, Maximum Power Production. For such reasons, the raindrop profile is the most important profile used in aerodynamic designs. A designer who cares about these factors must use the raindrop profile. Designing wings makes it possible to stay true to all of these factors. Therefore, our wing section must be in the raindrop profile.

In 1933, NACA published a publication about wing profile studies. In this publication, NACA described the 4-digit wing profile. These four steps according to this definition define the general shape of the wing profile. There are raindrop profiles that NASA has created as a result of its experiments for aircraft. These profiles were named by NACA, whose previous name is NASA. NACA 4415 who has minimum cw (air friction coefficient) is also used in the wing profile.

We have chosen design the wing section based on the raindrop shape which has the most appropriate aerodynamic structure.

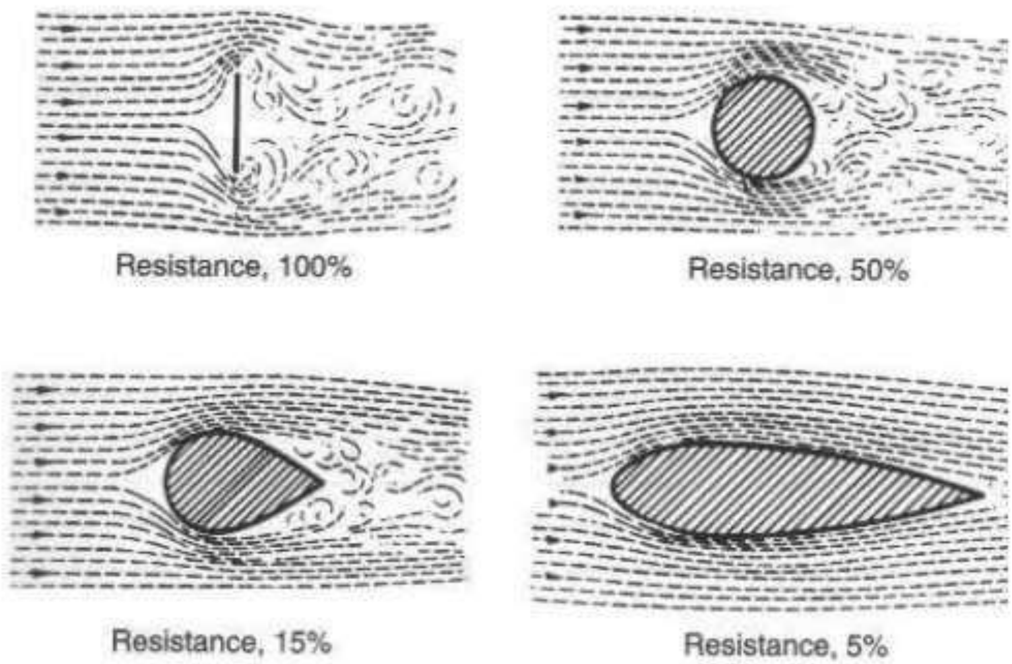


Figure 1. *Aerodynamic behavior of different geometries*

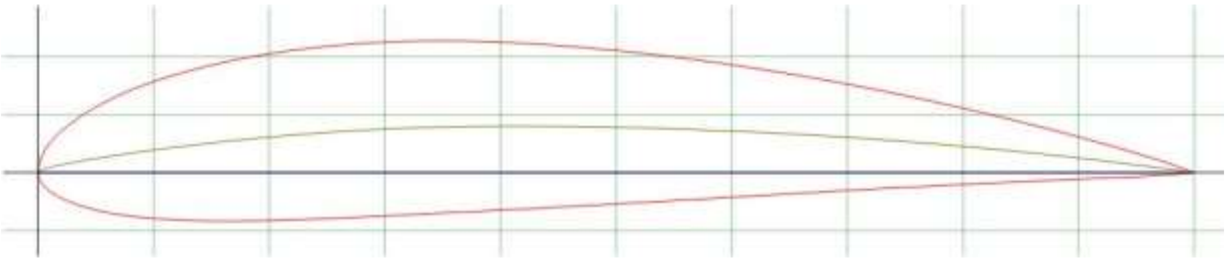


Figure 2. *NACA 4415 Raindrop profile [5]*

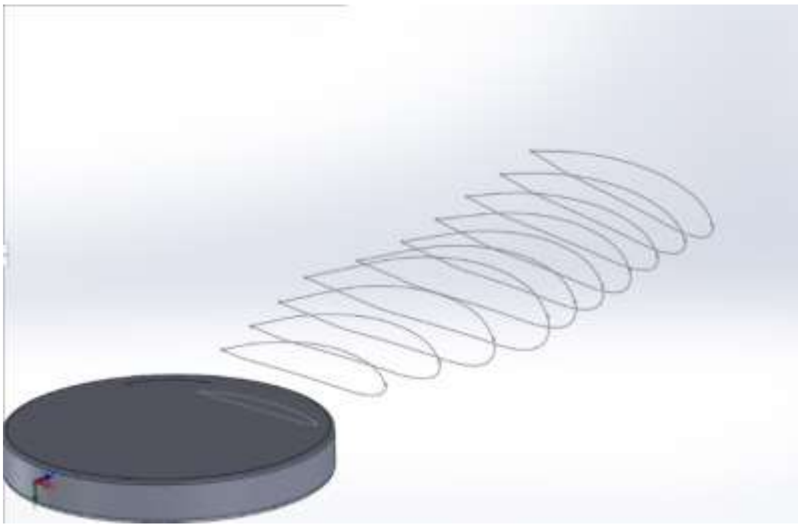


Figure 3. *Designed wing section structure*

As seen in the figure, when birds want to fly fast and they glide, slightly bend their wings in a V-shape. This reduces the contact surface of the flowing air to the wings and provides the most economical flight while increasing the air flow velocity from the body to the wing tips.

Figure 4. *The world's fastest flying bird Hen harrier*

Figure 5. *Eagle*

Figure 6. *Swallow*

Figure 7. *Hawk*

In fact, migratory birds fly together in a V-shape to achieve optimal aerodynamic movement. The researchers showed that birds used the airflow in the most efficient way by adjusting the wing movements to the nearest bird in the flock during the flight. During the ‘V-shape’ flight, it was understood that the birds' wing movements were compatible with each other, thus making the most of the upward airflow, when a bird was flying just behind the other, the harmony between the wing movements was lost and the effect of the downward airflow was minimized [6].

Figure 8. *Migratory birds*

With this observation, we were inspired by birds' wing design. The design was created in the form of raindrop wing section. 205/55 R16 wheel dimensions are used in our design. Design works were carried out in Solidworks program.

Figure 9. *Design with biomimetic approach*

4. FLOW ANALYSIS AND RESULTS

In 1999, researchers developed a software system called Hyperroad. They tested the Ferrari F550 and achieved consistent results. CFD software analysis data down to 1.8% error with updates [7]. This application can help improve an automobile's fuel economy and lower its emissions, reduce the environmental noise of aircraft, and increase the efficiency of wind turbines for power generation [8].

The analysis was performed in the Fluent Simulation command of the Solidworks program. Together with the rim we designed for analysis, we designed a standard rim model with the same dimensions. By comparing the analysis of these two rim models, we had the opportunity to observe the advantages of our design.

Figure 10. *Wing model designed for the analysis results*

The analysis parameters were 1 atm environmental pressure, 20 ° C temperature, wind speed of 33 m / s which affects to the wind speed of 120 km / h while the vehicle is going at 120 km / h. The wheel speed of 110 rad / sec, which corresponds to the vehicle's speed of 120 km / h, was used.

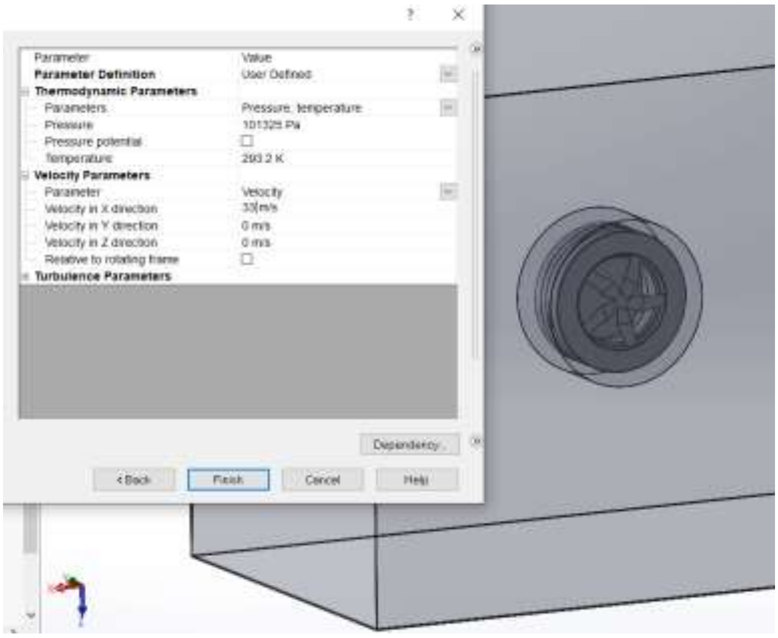


Figure 11. *Analysis parameters*

Our analysis results are shown in the following figures.

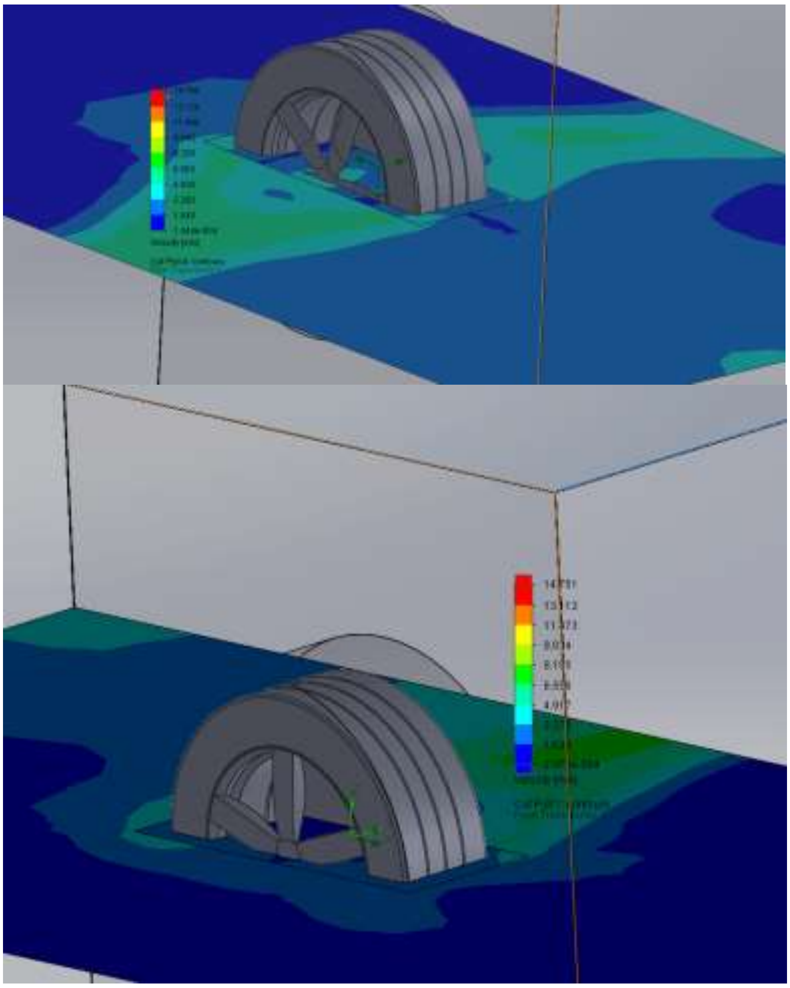


Figure 12. *Change of air in the analysis applied to the standard rim with the designed rim*

As shown in Figure 12, the air acting on the designed rim tends outwardly perpendicular to the whell. The amount of air entering is minimized relative to the other. In the other design, the air is filled into the rim.

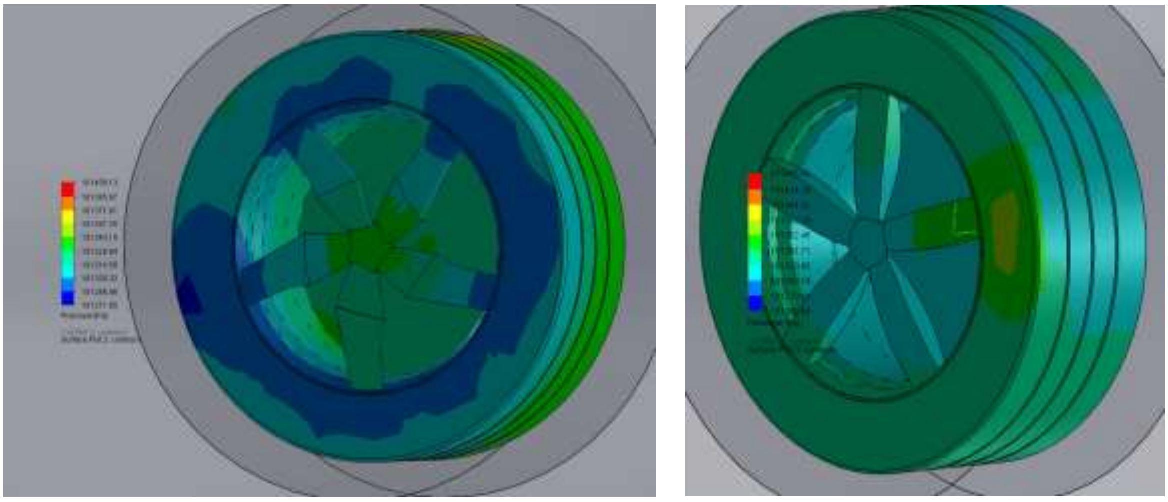
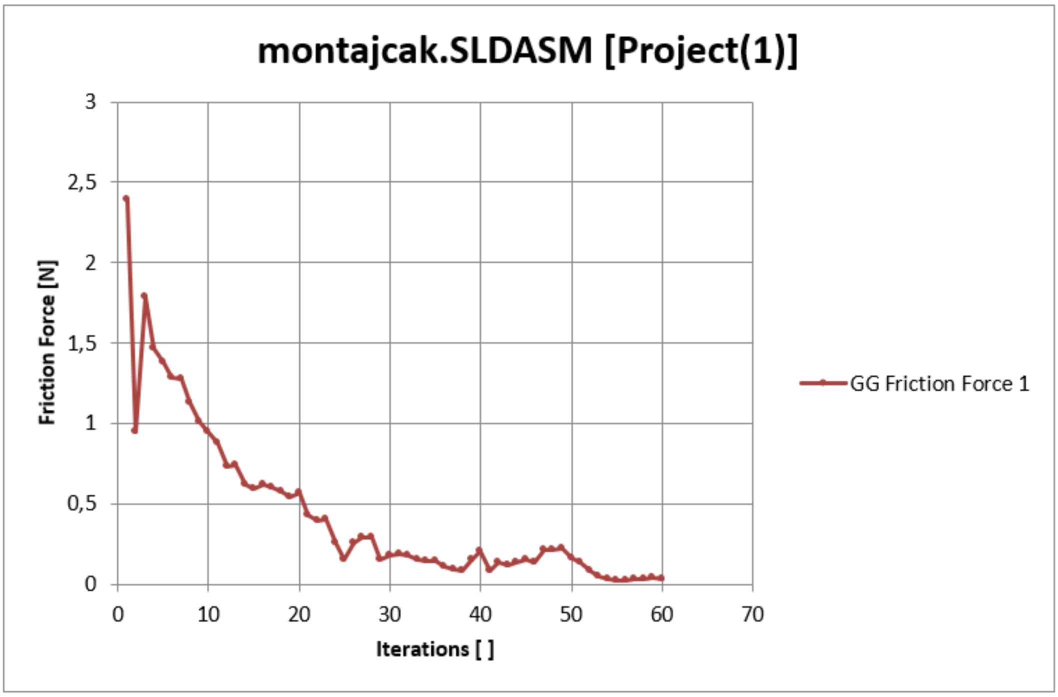


Figure 13. *Pressure force affecting on wheels*

In Figure 13, the regions shown in blue in our design on the left side are the regions where the pressure is the lowest. The pressure is highest in the wheel surface and in the rim hub, is the lowest on the rim wing tips. The pressure force in the right side on standard wheel is shown to be almost the same level everywhere.

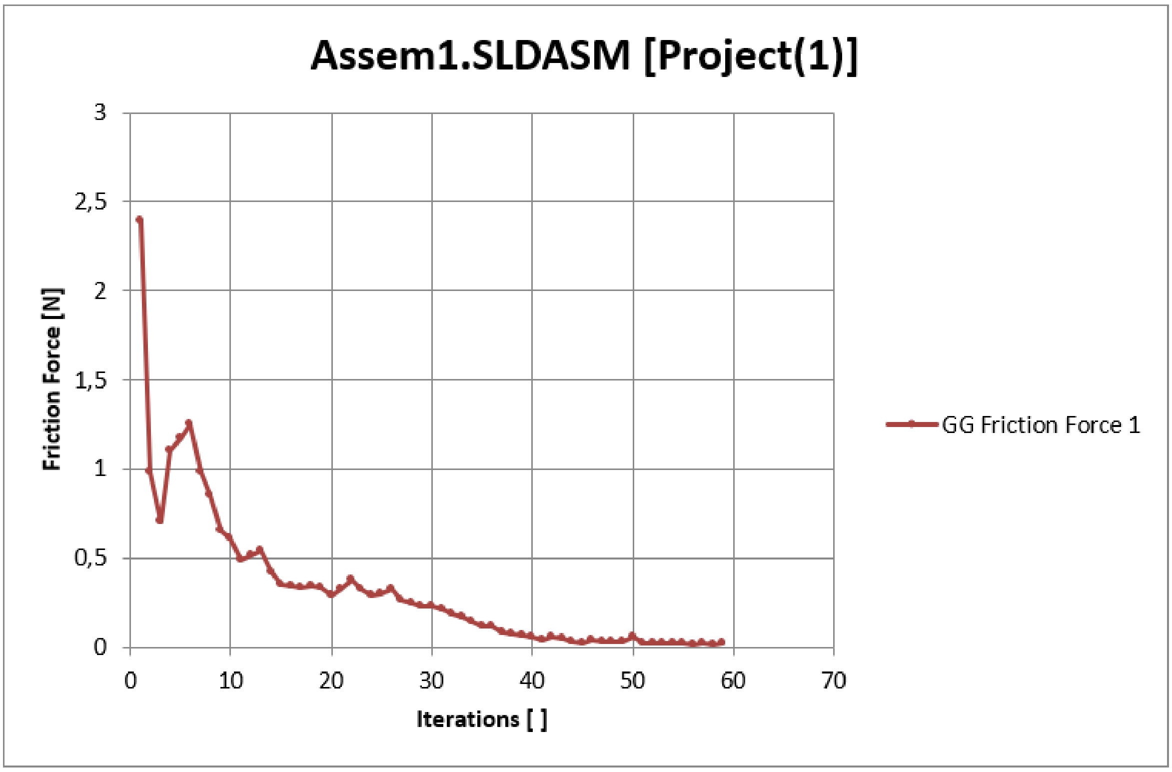
5. CONCLUSION AND DISCUSSION

Table 3. *Friction force and graph of the standard rim in the analysis*



Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value	Progress [%]	Use In Convergence	Delta	Criteria
GG Friction Force 1	[N]	0,033599914	0,1066891	0,020209924	0,218468025	100	Yes	0,106393681	0,25525732

Table 4. *Friction force and graph of the designed rim in the analysis*



Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value	Progress [%]	Use In Convergence	Delta	Criteria
GG Friction Force 1	[N]	0,020172636	0,033711883	0,016079807	0,0656147	100	Yes	0,049534893	0,178829691

In Table 3, the average friction force of the standard rim in the analysis was calculated as 0,1066891 N. In Table 4, the average friction force of the designed rim in the analysis was calculated as 0,033711883 N. It is seen that there is 68,4% gain in the friction force of the rim designed by taking the wing shape from the birds and the cross-sectional surface of the raindrop, according to the analysis parameters compared to a standard rim designed.

These analyzes show that the design inspired by birds' gliding wing movements reduces air resistance and has a positive effect on the aerodynamics of the wheel. Reducing this resistance force caused by air on the wheel will increase the fuel economy of the vehicle. Air entering the wheel will improve the braking performance by cooling the brake system during braking.

This design resulting is possible adapting to automotive, aerospace, renewable energy sources and similar sectors. This design can be further improved and optimized. In this way a design can result the lowest air friction.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

REFERENCES

[1] İnternet: https://www.wikitarih.com/sanayi-devrimi-nedenleri-sonuclari/

[2] Ersoy E., Küçükbayrak S., “21. yüzyılda bütün yönleri ile enerji”, Enerji Çevre İlişkisi Sempozyumu Bildiriler Kitabı s. 124-127, 1994.

[3] Marland, G., T.A. Boden, and R. J. Andres. "Global, Regional, and National CO2 Emissions" in Trends: A Compendium of Data on Global Change. Oak Ridge, Tenn., U.S.A.: Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, 2003.

[4] U.S. Energy Information Administration, International Energy Outlook, 2017.

[5] İnternet: www.AirfoilTools.com

[6] V is for vortex, *Nature Magazine*, 2014.

[7] İnternet: https://docplayer.biz.tr/63496247-2-1-2-gercekci-analiz-aerodinamik-kuvvetler-suruklenme-kuvveti-kaldirma-kuvveti.html

[8] İnternet: https://www.technologyrecord.com/Article/dassault-syst232mes-strengthens-its-simulation-offering-56976

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The Effect of Production Ergonomy on Product Quality in the Context of Built-in Oven Production Line

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Abstract

There are many studies discussing the issue of ergonomics in the context of sick leave and social expenditures. However, there are fewer studies linking production ergonomics with other factors such as quality and efficiency. It would be useful to discuss production ergonomics in a wider context. The study was carried out as a pilot study in a factory where a built-in oven was produced. The aim of the study is to show that there is a relationship between production ergonomics and the product quality produced in the factory. In the study, retrospective 20-week production line data were analyzed. As a result of the analysis, a series of quality errors were selected and the assembly tasks associated with these errors were determined. Aassembly tasks are classified by the company's Occupational Safety and Health Specialist as ergonomically appropriate or not ergonomically suitable for operators. When the difference between the number of errors related to the ergonomic categories is examined, it is found that there are three times more errors in ergonomically inappropriate tasks compared to ergonomically appropriate tasks. The work to be done to make the ergonomically inappropriate tasks suitable, the time plan and the responsible people were determined. The results of the study showed that there is a relationship between product quality and production ergonomics. The calculations in the study showed that the error rate would decrease by 90% in ergonomically optimized tasks; thus, business management has made a positive decision to invest in equipment to the relevant workstations. In return for the investment cost in the study, resources are used for value generating works and an increase in the number of correctly produced products is guaranteed.

1. INTRODUCTION

While production ergonomics is often associated with staff health and social expenditure, other factors that may be affected by inadequate ergonomics are rarely considered. The cost of improvements in production ergonomics is often compared to increased efficiency and quality gains. This study aims to focus on other possible savings and improvements from improved production ergonomics. The results will lead to a broader focus on management's perspective and a focus on production ergonomics in the context of the generally unattributed ergonomics-error rate. The results of the study aim to show that production ergonomics should be included more in the daily work and strategic works of the companies.

This pilot study focused on production ergonomics. The aim is to make production ergonomics an indicator that is continuously improved and monitored within the factory. In production ergonomics, there is a need to show what will be achieved after investments. As a result of the potential gains to be achieved, management's interest and participation in production ergonomics will increase; this will provide greater interest and funding for production ergonomics improvements.

The costs of product returns caused by quality defects because of the ergonomically impractical tasks of the assembly operators must be monitored by the factory management. In this way, a financial value can be obtained in order to compare the situation after improvement. These cost comparisons make it easier to

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present the importance of production ergonomics to management. Since the design of the product forms the basis for the ergonomic situation in the manufacturing business, it is equally important to forward the message to the product development departments.

In the start of this pilot study, the Company's objective is to facilitate communication on production ergonomics and to draw attention to the field of production ergonomics. After demonstrating the relationship between production ergonomics and quality results, the benefits of ergonomics can be defined as the reduction of costs caused by insufficient quality. The aim of the study is to convey the importance of production ergonomics to managers and product development department employees. It also provides additional data to confirm the link between production ergonomics and product quality. A deeper study is needed to clearly demonstrate the financial benefits of production ergonomics. The objectives of this study are as follows:

1. To demonstrate the relationship between production ergonomics and product quality in the context of built-in oven assembly
2. Convey the results of improvement and the importance of production ergonomics to managers and product development department employees

This study is considered as a pilot; possible benefits and constraints that are expected to be followed by ergonomics improvement studies are mentioned.

2. EFFECT OF PHYSICAL ERGONOMICS ON PRODUCT QUALITY

With the increase in the number of products in the market, production companies must be competitive in order to survive. The success of company in a competitive industrial market depends on improving employee health, efficiency and quality (Törnström et al., 2008). In order to ensure the continuity of companies in the competitive market, production systems are established to maximize profit by increasing efficiency and quality. In the meantime, ergonomics is often ignored. Ergonomics have become important in the industry as ergonomic non-conformities affect quality, cost and efficiency (Akay et al., 2003). At the same time, it is necessary to make the working environment ergonomically suitable to prevent physical and mental illnesses and to reduce operating costs (Şahin et al., 2017). Ergonomics integrated into a lean manufacturing system installed in a Brazilian automobile factory (Vieira et al., 2012). While the system includes 5S, quality control, kaizen and standardization, researchers added ergonomics to the system. As a result of the study, it was found that the rate of vehicles leaving the production line without the need for re-maintenance increased from 48% to 78% after the addition of ergonomics to the system. (Vieira et al., 2012). The positive effects of ergonomic improvements on quality and costs have emerged as a result of the studies. In a study conducted by Yeow and Sen (2006) in an electronics factory, it was observed that the quality errors detected in production decreased by 30% as a result of improvements aimed at improving low-cost physical ergonomics. At the same time, the reduction in quality errors that occurred in the end user was 11%. On the other hand, productivity increased by 50% and the factory's annual profit increased by USD 950,000.

A study by Falck (2009) at an automobile manufacturer has shown that an ergonomically inappropriate task causes more errors than an ergonomically suitable task. The study was started by mapping the ergonomic situation. The tasks are divided into three different classes according to their ergonomic status. These three classes are symbolized by traffic lights. Green light represents ergonomically good conditions; yellow light represents ergonomically neither good nor bad situations; red light represents poor ergonomically conditions. As many jobs as possible were received from each class, tasks were randomly selected. Then, the errors occurred during the tasks of this selected ergonomic classes were monitored. It was found that the time taken to complete each task was different between the classification levels. The longest tasks belong to the yellow class and the shortest tasks belong to the green class. The numbers are set so that a comparison can be made. As a result, it was found that there were fewer errors in green tasks compared to yellow and red tasks. A similar study was conducted by Almgren and Schauring (2012) at the Volvo Truck Manufacturing plant. Assembly tasks are divided into two categories as red and green tasks; yellow tasks were excluded from the analysis. As a result, the average quality error occurrence time in the red category assembly tasks is 12.68 errors/minute; the average quality error occurring time for assembly tasks in the green category was calculated as 4.79 errors/minute. When the ergonomic difficulty increases, the frequency of quality errors increases. These findings show that ergonomics has a significant effect on quality outputs.

The strong link between quality errors and high ergonomic risks has been demonstrated by other studies (Falck et al, 2010, Falck and Rosenqvist, 2014, Fritzsche et al., 2014). As a result of the studies carried out in Volvo car production plant in 2010, a strong relationship was found between inappropriate ergonomic conditions and quality defects. Of the 352 quality problems recorded in the production phase of three new car models, 23.5% were associated with ergonomic problems (Falck et al., 2010). In another study conducted in the automobile manufacturing plant, 47 assembly tasks were analyzed. As a result, the error rate was 55.1% for tasks with high ergonomic workload, 37.8% for tasks with medium ergonomic workload and 7.1% for tasks with low ergonomic workload (Falck and Rosenqvist, 2014).

Most ergonomists are concerned that ergonomic assessments are not carried out at the design stage. Ergonomic assessments are usually made after strategic decisions have been made, at a point where any changes will significantly increase costs. As a result, ergonomic improvement remains only in the size of small adaptations; the entire ergonomics process is seen as time-consuming and cost-effective. Another problem is that feedback caused by improper ergonomics persists in the form of sick leave, injuries, even a few years after the design process is completed. The relevance of these results to design is not clear at the management level. In addition, these feedbacks often do not reach the design team at all and therefore do not provide in-house learning (Dul and Neumann, 2009). Adjusting the workplace measurements according to the human body measurements will provide an increase in productivity (Eldem et al., 2019; Eldem, Sahin and Top, 2019).

According to a comparison by Auburn Engineers, an American consulting firm, the cost is 1% of the budget if ergonomics specialists are involved from the beginning; the inclusion of the system after the commissioning is a cost of 12% of the budget. If problems are addressed before the system is commissioned, changes are easier and less costly, making the total cost less (Hendrick, 2003).

3. REBA (RAPID ENTIRE BODY ASSESMENT) METHOD

REBA was proposed by Hignet and McAttamney (2000) as a requirement by observing the variable working positions of employees in the health care and other service industries in the UK. REBA is a quick and easy method to evaluate various work positions for work-related musculoskeletal disorders (Madani and Dabahneh, 2016). Divides the body into sections to be coded independently according to the motion planes and provides a scoring system for muscle activity throughout the body, in a stagnant, dynamic, fast changing or unstable manner and A handling score is used when manual handling occurs because the load is carried (Hignet and McAttamney, 2000). Only paper and pen are required when applying REBA (Madani and Dabahneh, 2016).

Before the application with some practice and after training REBA can be used by ergonomists and other practitioners (David, 2005). In Reba method, measurement of body posture joint angles is analyzed by observing force load and repetition of movements and frequency of posture change (Al Madani and Dababneh, 2016). Neck, trunk, upper and lower arms, leg and wrist positions are divided into certain value ranges. The score of each position corresponding to the evaluated anatomical areas increases as the segment moves away from the neutral position.

Table A score is the sum of the posture scores for the trunk, neck and leg and the load / force score (Figure 3.1). Group A includes 60 posture combinations of body, neck and leg positions (Table 3.1). The score obtained by adding the load / force score is between 1-9.

Table 3.1. *Reba Form A Table (Hedge, 2000)*

Neck Score

Table A		Neck											
		1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

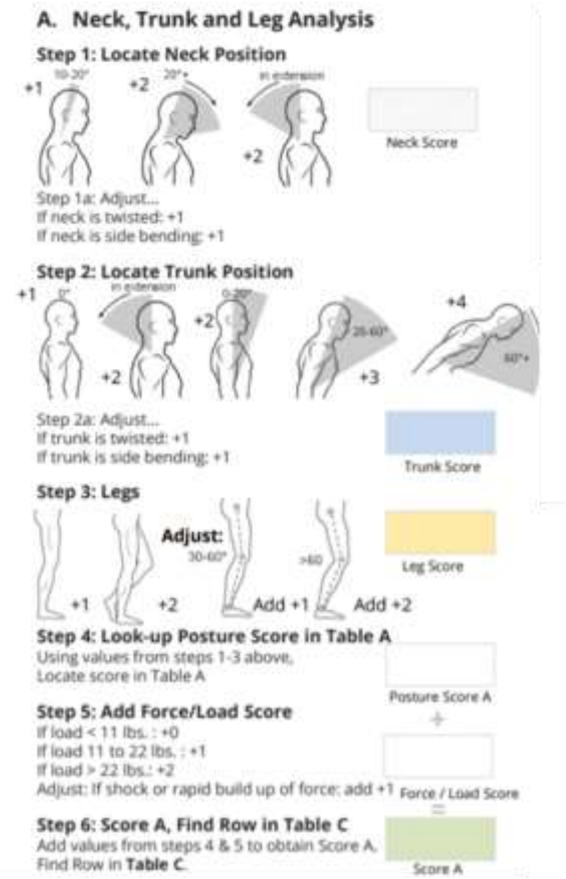

Figure 3.1. *Scores of the positions of the neck, trunk and legs (Hedge, 2000)*

Score B is the sum of the posture points for the upper arms, lower arms and wrists and the holding score for each hand (Figure 3.2). Group B has a total of 36 different posture combinations for the upper arms, lower arms and wrists (Table 3.2). The result score is obtained by obtaining the holding score.

Table 3.2. *Reba Form B Table (Hedge, 2000)*

Table B		Lower Arm					
		1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

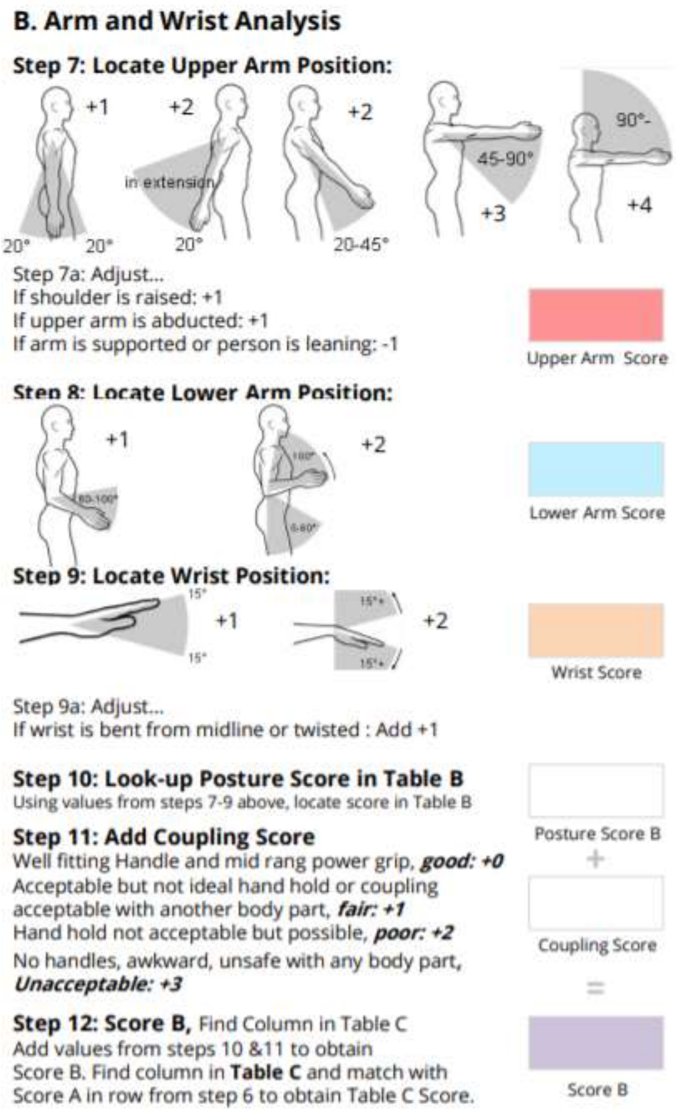

Figure 3.2. *Scores of lower-upper arm and wrist positions (Hedge, 2000)*

The A and B scores are combined in Table C (Table 3.3) to achieve a total of 144 combinations and finally an activity intensity score is added to achieve the ultimate REBA score (Figure 3.3).

Table 3.3. *Reba Form C Table (Hedge, 2000)*

Score A	Table C											
	Score B											
	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score + Activity Score = REBA Score

Step 12: Score B, Find Column in Table C
Add values from steps 10 &11 to obtain
Score B. Find column in **Table C** and match with
Score A in row from step 6 to obtain Table C Score.

Score B

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
+1 Action causes rapid large range changes in postures or unstable base

Figure 3.3. *Activity intensity score values (Hedge, 2000)*

Final score is evaluated in 4 different categories (Figure 3.4). Value [1-4] means low risk. Value [5-7] is considered as high risk; requires change in medium term. Value [8-10] means high risk. It requires a detailed examination of the working position and the commissioning of improvements. When the score [11 and above] is calculated, the position involves a very high risk. The necessary changes must be put into emergency operation.

Scoring
1 = Negligible Risk
2-3 = Low Risk. Change may be needed.
4-7 = Medium Risk. Further Investigate. Change Soon.
8-10 = High Risk. Investigate and Implement Change
11+ = Very High Risk. Implement Change

Figure 3.4. *Reba evaluation final score rating (Hedge, 2000)*

4. METHODOLOGY

The pilot study consists of two main parts:

1. Data collection
2. Data Analysis

4.1. Data Collection

One of the 12 production lines in which the built-in oven is produced is identified as pilot band. The layout of the production line is shown in Figure 4.1.

Figure 4.1. *Built-in oven production line layout*

The production line consists of 18 main and 2 side stations. In the study, quality errors of the products produced in the assembly line in the past 20 weeks were collected. Errors were classified according to the station at which they occurred. The tasks performed at each station are classified as ergonomically suitable or ergonomically unsuitable for operators by the occupational safety and health specialist.

4.2. Data Analysis

Two stations with the highest number of error occurrences were detected. These are glasswool assembly and circulation motor grouping sheet assembly stations. At glasswool assembly station, operatör carries the glasswool-assemblied cavity on his shoulder and transport it to the sliding belt.

While carrying the cavity over his shoulder, the operator cannot carry out the task of checking the quality of the enamel inside the cavity defined for this station. When the quality control results of the products are evaluated, a high rate of enamel defects in cavity is encountered. If the operator is allowed to visually check the inside of the cavity during transport, the defective cavities can be sorted out at this station.
REBA evaluation of the station was completed (Figure 4.2). As a result of the evaluation, REBA score was calculated as 9. The station is not ergonomically suitable; detailed review and necessary improvements are needed. For this purpose, an arrangement has been designed to facilitate the operator to transport the cavity to the sliding belt.

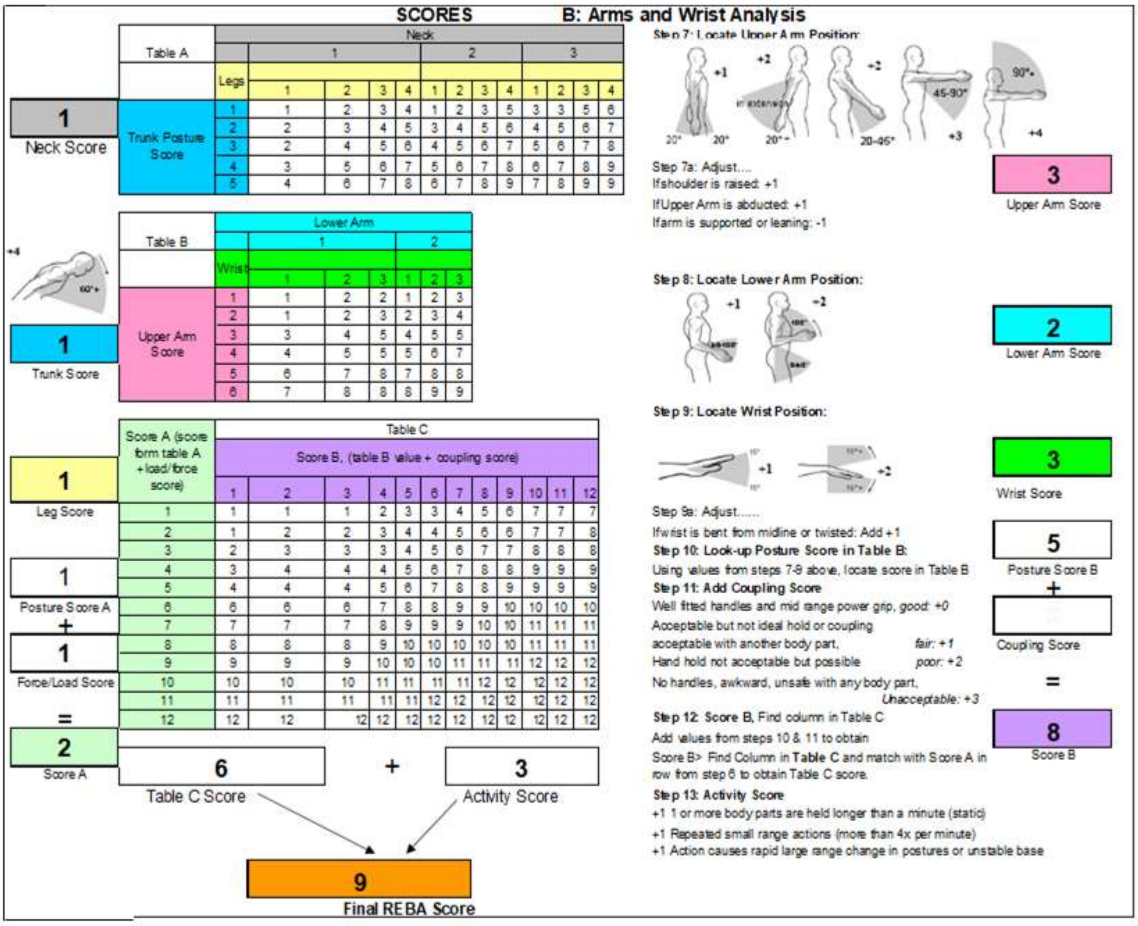

Figure 4.2. *REBA evaluation of glasswool assembly station*

Latched manipulator investment was made to the station for improvement (Figure 4.3). Cavity load was lifted from operator.

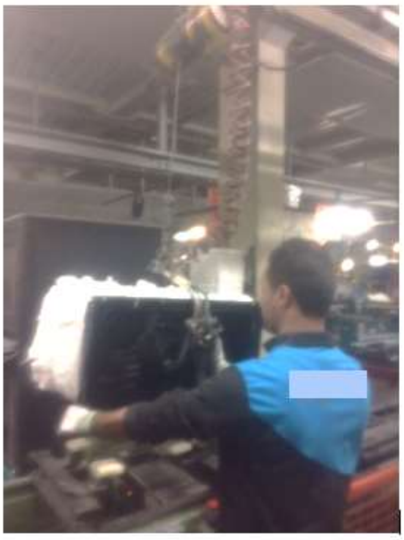

Figure 4.3. *Moving the cavity with the help of latched manipulator*

As a result of the REBA Assessment after the improvement, the risk score was calculated as 3 (Figure 4.4).

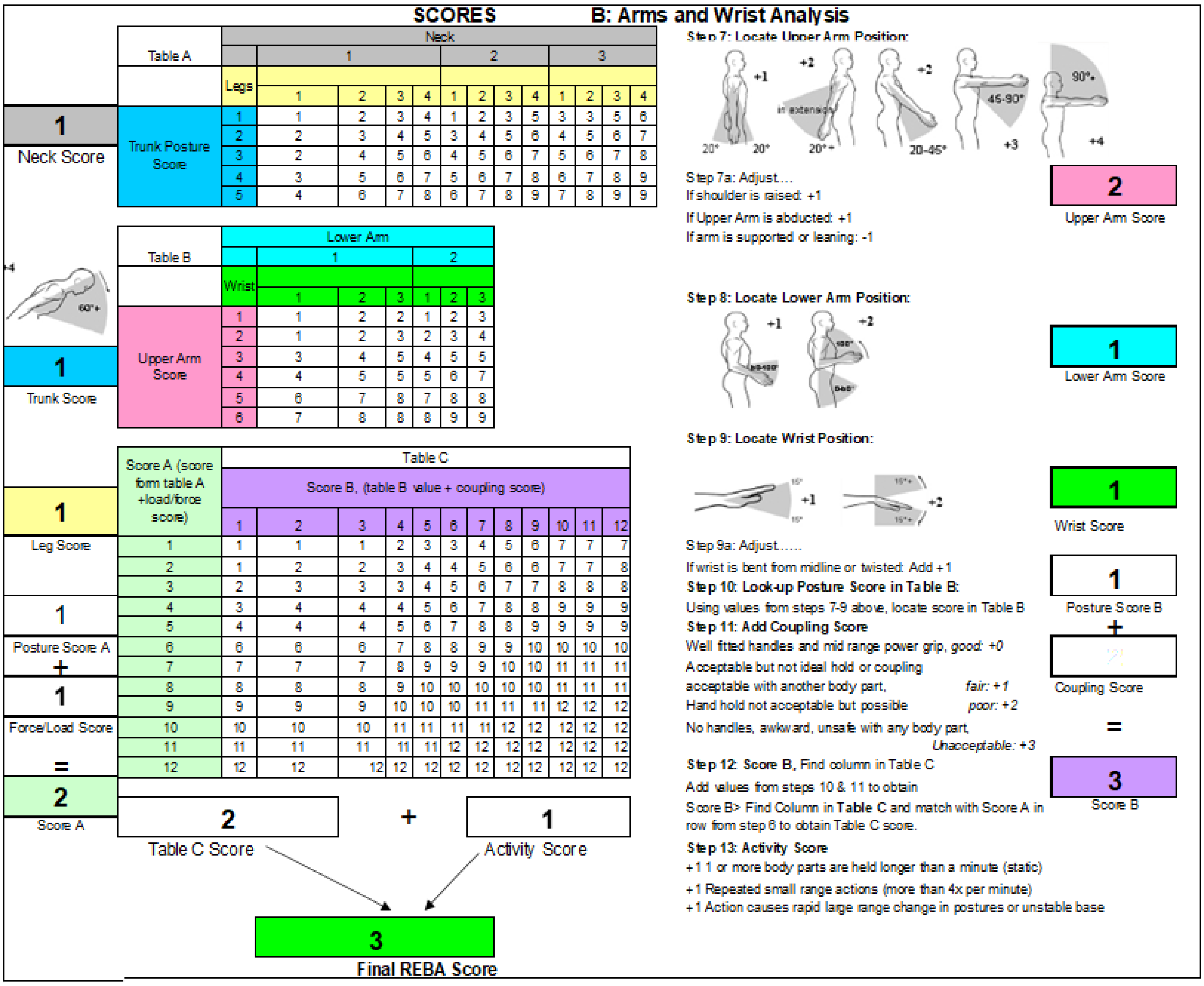

Figure 4.4. *REBA evaluation at the glasswool assembly station after improvement*

The cavity is held by the latch of the manipulator and the cavity is raised to the eye level of the operator by means of the handle. Since the operator can easily see inside of the cavity, it can easily detect enamel defects and defective cavities can be separated at this station.

The second station with the highest quality errors in the study is circulation motor grouping sheet assembly station (Figure 4.5). In this station, the operator bends to group the enamel-coated rectangular sheet into the frame and throws 4 screws, one in each corner. During operation, the circulation motor grouping sheet cannot be grouped properly as the screw enters the target point mostly inclined. The improperly grouped circulation motor grouping sheet causes a disturbing noise during operation of the built-in oven. As a result of the first REBA evaluation at the relevant station, the REBA score was calculated as 7.

Figure 4.5. *Circulation motor grouping sheet assembly operation*

A mechanism was used to raise the station to the level and angle at which the operator can easily screw (Figure 4.6). The device is controlled by the foot pedal. The cavity is held up by the 2 suction cups in the mechanism. Then, with the help of servo motors connected to the device, it keeps the cavity up and inclined at an angle suitable for the operator's viewing angle. When the assembly is completed, the device is commanded again by using the foot pedal.The cavity is lowered and released by the mechanism to the assembly line.

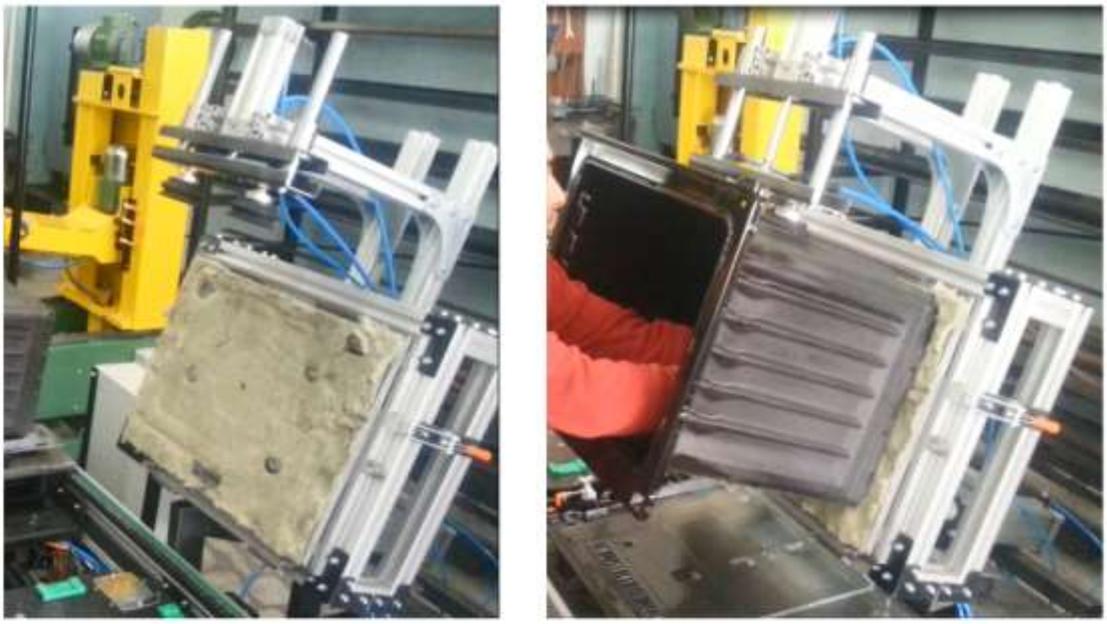

Figure 4.6. *Circulation motor grouping sheet assembly at the right height and angle*

At the respective station, the device grips and lifts the cavity with the arms on both sides and inclines backwards. In this way, the operator clearly and easily sees the points to be screwed. REBA score of the station after improvement was calculated as 3; ergonomic risk ratio is low. The number of errors occurred after the improvements were examined. It has been observed that the number of errors occurring at the relevant station decreased by 90%.

5. RESULTS

Analyzes in the study showed that the error rate decreased by 90% in ergonomically optimized tasks. By demonstrating the relationship between production ergonomics and quality results, the benefits of ergonomics can be defined as the reduced cost of poor quality for companies. This pilot study demonstrates the potential to improve production ergonomics in plants to manufacturing companies. It has also contributed to the diversity of studies demonstrating the link between production ergonomics and factors other than health and social spending. Only physical ergonomics was included in the study. The parts of cognitive ergonomics such as mental stress, information processing and autonomy were not included in the study.

In summary, two objectives were aimed in this study:

1. To demonstrate the relationship between production ergonomics and product quality in the context of built-in oven assembly
2. Present the results of improvement and the importance of production ergonomics to managers and product development department employees.

It has been shown that there is a relationship between production ergonomics and quality results since the error rate detected per product is reduced in ergonomically optimized stations.

In order to achieve the second objective, the results of the study must be returned as financial gain. This gain is calculated by adding up the cost of man-hours spent on repairing the defects and the cost of the material used. The reduction in error rate associated with the improvement of ergonomically inappropriate tasks and reduction in repair costs are presented as post-improvement savings. The savings from the reduction in repair costs can be used to increase ergonomic improvements.

Since no studies on cognitive ergonomics have been conducted in the factory so far, this field has been avoided. Further studies in the field of cognitive ergonomics are necessary. The ergonomic status in production has been scored by REBA method by experts in Production Engineering Management and Occupational Safety and Health; tasks completed in the assembly stations is divided into tasks and sub-tasks.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors

REFERENCES

Almgren, J., Schaurig, C. (2012). The influence of production ergonomics on product quality (Unpublished master’s thesis). *Chalmers University of Technology*, Gothenburg, Sweden.

Al Madani, D., Dababneh, A. (2016). Rapid entire body assessment: a literature review. *American Journal of Engineering and Applied Sciences*, 9(1), 107-118.

Bohgard, M., Karlsson, S., Lovén, E., Mikaelsson, L. Å., Mårtensson, L., Osvalder, A. L., ... & Ulfvengren, P. (2015). Work and technology on human terms. *Prevent*.

David, G. C. (2005). Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders. *Occupational medicine*, 55(3), 190-199.

Akay, D., Dağdeviren, M. Kurt, M. (2003). Çalişma duruşlarinin ergonomik analizi. *Gazi Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi*, 18(3).

Dul, J., Neumann, W. P. (2009). Ergonomics contributions to company strategies. *Applied ergonomics*, 40(4), 745-752.

Eldem, C., Şahin, İ., Demir, M. T., Top N., Şahin, T. (2019). Araç Bakim Kanallarinin Dijital İnsan Modelleri ile Ergonomik Analizi ve Yeniden Tasarimi. *Mühendislik Bilimleri ve Tasarım Dergisi*, 7(2), 386-392.

Eldem, C , Top, N , Şahin, H. (2019). A Study on Ergonomic Assessment of Automobile Driver Posture Positions Using Digital Human Models, *Gazi Journal of Engineering Sciences*, 5 (1) , 22-31.

Falck, A. C. (2009). Ergonomics methods and work procedures in car manufacturing for improvement of quality, productivity and health at work. *Chalmers University of Technology*.

Falck, A. C., Örtengren, R., Högberg, D. (2010). The impact of poor assembly ergonomics on product quality: A cost–benefit analysis in car manufacturing. *Human Factors and Ergonomics in Manufacturing & Service Industries*, 20(1), 24-41.

Falck, A. C., Rosenqvist, M. (2014). A model for calculation of the costs of poor assembly ergonomics (part 1). *International Journal of Industrial Ergonomics*, 44(1), 140-147.

Fritzsche, L., Wegge, J., Schmauder, M., Kliegel, M., & Schmidt, K. H. (2014). Good ergonomics and team diversity reduce absenteeism and errors in car manufacturing. *Ergonomics*, 57(2), 148-161.

Haslegrave, C. M., Pheasant, S. (2005). Bodyspace: anthropometry, ergonomics and the design of work.

Hedge, A. (2000). REBA Employee Assessment Worksheet. Retrieved October 25, 2018, from https://ergo-plus.com/wp-content/uploads/REBA.pdf.

Hendrick, H. W. (2003). Determining the cost–benefits of ergonomics projects and factors that lead to their success. *Applied ergonomics*, 34(5), 419-427.

Hignett, S., McAtamney, L. (2000). Rapid entire body assessment (REBA). *Applied ergonomics*, 31(2), 201-205.

Şahin, İ., Eldem, C., Kalyon, S. A., Gökçe, H. (2017). Digital Human Modelling and Ergonomic Analysis: Automatic Arm Barrier as an Example. In *International Congress on New Trends in Sicence, Engineering and Technology*, Barcelona, Spain (pp. 176-187).

Törnström, L., Amprazis, J., Christmansson, M., Eklund, J. (2008). A corporate workplace model for ergonomic assessments and improvements. *Applied ergonomics*, 39(2), 219-228.

Vieira, L., Balbinotti, G., Varasquin, A., Gontijo, L. (2012). Ergonomics and Kaizen as strategies for competitiveness: a theoretical and practical in an automotive industry. *Work*, 41(Supplement 1), 1756-1762.

Yeow, P. H., Sen, R. N. (2006). Productivity and quality improvements, revenue increment, and rejection cost reduction in the manual component insertion lines through the application of ergonomics. *International journal of industrial ergonomics*, 36(4), 367-377.