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COMPARISON OF TWO DIFFERENT WAFER BAKING PLATE LOCKING MECHANISMS IN WAFER FURNACES IN TERMS OF STRESSES

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Abstract:
A wafer baking plate is set in wafer ovens, and wafer dough is baked to produce wafer sheets. Since wafer dough contains more than 50% water and is baked in a closed environment, it creates high pressure over time. This pressure puts considerable strain on the wafer baking plate and locking mechanisms and adversely affects the locking mechanism. In this case, it is necessary to calculate the stresses and displacements on the parts by modelling the loads and the boundary conditions specific to the problem for various plate locking mechanisms. This study used the finite element method to calculate and compare the stress and displacement values on two different locking mechanisms of a wafer baking plate. As a result of the analysis, the Von Mises stress value of the butterfly lock mechanism was 34.5% higher than the hook lock mechanism. The displacement value of the hook lock mechanism is 9.5% lower than the butterfly lock mechanism. Since the total contact area of the butterfly lock mechanism is shallow and the Von Mises stress value is higher than the other mechanism, it is predicted that the wear will be higher in continuous operation.

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1. INTRODUCTION

Wafer baking ovens are essential machines in the wafer production line. The most important mechanical component of these ovens is the wafer baking plates. These plates move on rails connected and are heated with the help of burning stoves located under the plates. Wafer batter is poured between the two heated casting plates to produce wafer leaves. The wafer batter contains 52-58% water, and water vapor are produced during cooking between the closed hot plates (150-180°C) [1,2]. Studies have observed that the water vapor formed in closed hot plates creates a pressure of 1-1.3 bar [2]. Fig. 1 shows the pressure change created by the liquid dough in the baking plate depending on the baking time.

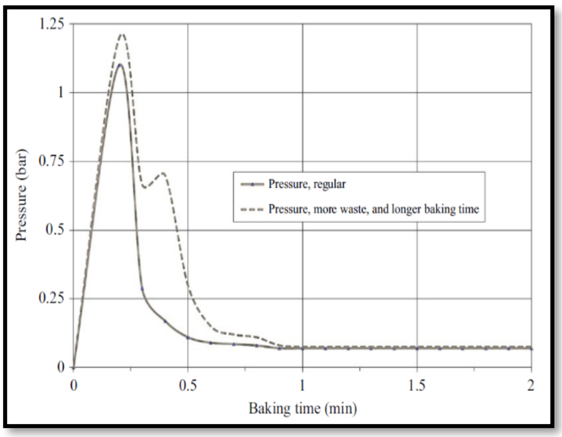

Fig. 1. Pressure changes of liquid dough in the baking plate depending on the baking time [2]

Wafer baking plates are made of cast materials due to their high strength and near-homogeneous

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heat dissipation. Along with the superior advantages of the mechanical properties of cast iron, its heavy weight is also an important disadvantage [2-4]. For example, a 350x500 mm wafer baking plate has an approximate mass of 220 kg. Wafer baking plates have three main parts: tongs, plate and locking mechanism. There are many types of locking mechanisms of wafer baking plates today [5]. The industry's most commonly used locking mechanism is the so-called butterfly locking mechanism. Fig. 2 shows the images of two plates with the same plate geometry, one with a butterfly locking mechanism and the other with a hook locking mechanism.

(a)

(b)

Fig. 2. Visualization of identical wafer baking plates with different locking mechanisms, a) butterfly locking mechanism, b) hook locking mechanism [6]

As soon as the hot baking plates receive the liquid dough, the plate closes and the mechanical locking mechanism is activated. The cast plate is exposed to steam pressure, thermal effects and reverse mass loads during baking. Steam pressure, in particular, is known to increase pressure's effect on the mass's load and force the plate locking mechanism with reverse force [5].

Due to these operating conditions, the locking mechanism wears out quickly. Worn locking mechanisms have a negative impact on wafer production performance. Due to the effects mentioned above, friction and stable operating conditions, the locking mechanism wears out over time. The wear problem in the locking mechanism is directly related to the stress on the mechanism. Therefore, reducing the stress level in the lock mechanism will also improve the wear performance. In the case of heterogeneous vapor, a release may result in colour shade difference and variation of brittleness over the wafer sheet besides sticking to baking plates due to excess moisture [7-10]. Therefore, worn locking parts may affect the vapor evacuation, resulting in the problems mentioned above and uneven thickness distribution. This is the main focus of this study. Therefore, it is of utmost importance that the locking system is designed safely so that the operation and performance of the entire furnace system are not adversely affected.

In the literature, there are many studies in which different/same materials with different/same designs are evaluated on stresses by the finite element method. They investigated the effects of varying notch sizes with the same geometry on the plastic region and fatigue due to different superalloy materials [11]. Other researchers also investigated the temperature and conjugate stress differences of wafer baking plates containing different casting materials with the same design during wafer baking by the finite element method [12]. At the end of the study, they found that both the time-dependent temperature data and the conjugate stresses of vermicular cast iron meet both parameters at an acceptable level. A mass lightning study was conducted by analyzing the loads on the wafer oven frames using the finite element method. As a result of the analysis of the existing chassis design, they reduced the mass of the existing chassis by 29.6% by making design changes in the excess regions where the stress is low [3]. Other researchers compared dental implants with different geometries by subjecting them to variable loads in finite element analysis, calculating the maximum compressive stress and maximum tensile stress of dental implants in bone [13].

The finite element method is an accepted numerical method with applications in many engineering fields. It has found application not only in solving mechanical problems but also in biotechnology and food science [14-20].

This study aims to find the effects of two different geometries of plate locking mechanisms with the same boundary conditions on the conjugate stress and displacement by the finite element method.

2. MATERIALS AND METHOD

This study uses the finite element method to investigate the behavior of a wafer baking plate with a butterfly lock mechanism under mechanical loads. In the study, the material of the butterfly lock mechanism is AISI 1040, and the material of the hook lock mechanism is GGG-45. The characteristic mechanical properties of AISI 1040 and GGG-45 materials provided by the supplier are given in Table 1 and Table 2, respectively.

Table 1. Mechanical Properties of AISI 1040

Properties	Values	Units
Elasticity Modulus	2e+011	N/m^2
Poisson Ratio	0.29	None
Shear Modulus	8e+010	N/m^2
Density	7700	Kg/m^3
Tensile Strenght	75e+07	N/m^2
Shear Strenght	45e+07	N/m^2
Coefficient of Thermal Expansion	1.15e-05	1/K
Thermal Conductivity	25	W/(mK)
Specific Heat	460	J/(kgK)

Table 2. Mechanical properties of GGG-45

Properties	Values	Units
Elasticity modulus	2.1e+011	N/m^2
Poisson Ratio	0.26	None
Shear Modulus	6.5e +09	N/m^2
Density	7250	Kg/m^3
Tensile Strenght	40e+07	N/m^2
Shear Strenght	25e+07	N/m^2
Coefficient of Thermal Expansion	1.1e-05	1/K
Thermal Conductivity	58	W/(mK)
Specific heat	460	J/(kgK)

In the finite element analysis of the 3D designs of the butterfly lock mechanisms and hook lock designs, the boundary conditions were completed by determining the fixed regions, built-in hinge regions, force values and regions. A force value of 27 kN was defined for both mechanisms, corresponding to the maximum force form due to the maximum pressure of 1.5 bar exerted on die faces during cooking. Fig. 3 shows the boundary and load conditions applied to the butterfly lock mechanism.

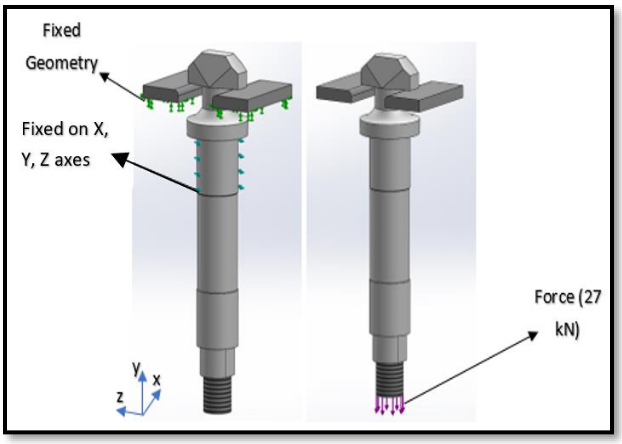


Fig. 3. Boundary and force conditions applying to the butterfly lock mechanism

Boundary and force conditions applied to the butterfly lock mechanism are shown in Fig. 4.

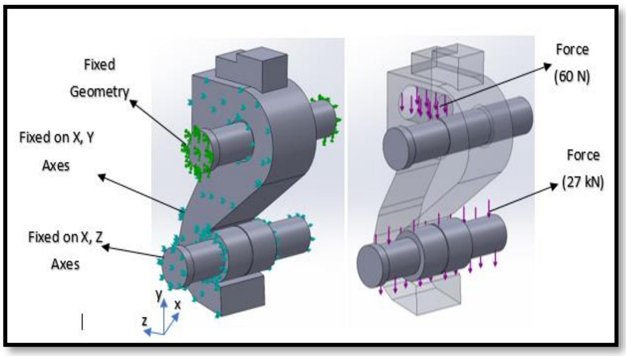


Fig. 4. Boundary and force conditions applying to hook lock mechanism

In the finite element analysis software (SolidWorks Simulation), mesh triangular prismatic elements were used in both mechanisms. The mesh structure of the butterfly lock mechanism was created such that the proportion of elements with aspect ratio <3, mesh pattern quality 99.6%, the total number of elements is 122830, and the total number of nodes 181595. The proportion of elements with an aspect ratio <3; the hook lock mechanism was created such that the network pattern quality was 99.9%, the total number of elements was 341930, and the total number of nodes was 495082. Fig. 5 shows the axial sub-stress components of the Von Mises conjugate stress.

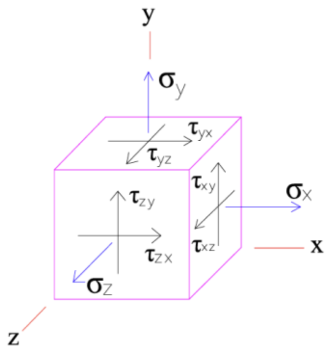


Fig. 5. Axial sub-stress components of Von Mises conjugate stress

The mathematical model and explanations for determining of the Von Mises conjugate stress given in Fig. 5 with the axial sub-stress component are presented in Eq. 1.

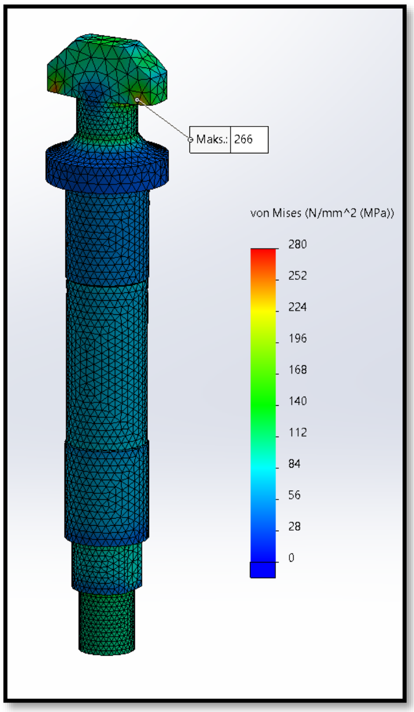
$$\sigma_{vm} = \sqrt{\frac{1}{2}\left[(\sigma_y-\sigma_y)^2+(\sigma_y-\sigma_z)^2+(\sigma_z-\sigma_x)^2\right] + 3(\tau_{xz}^2+\tau_{yz}^2+\tau_{yz}^2)} \quad (1)$$

$$\tau_{xy}, \tau_{yz}, \tau_{zx} = Shear\ Stresses$$

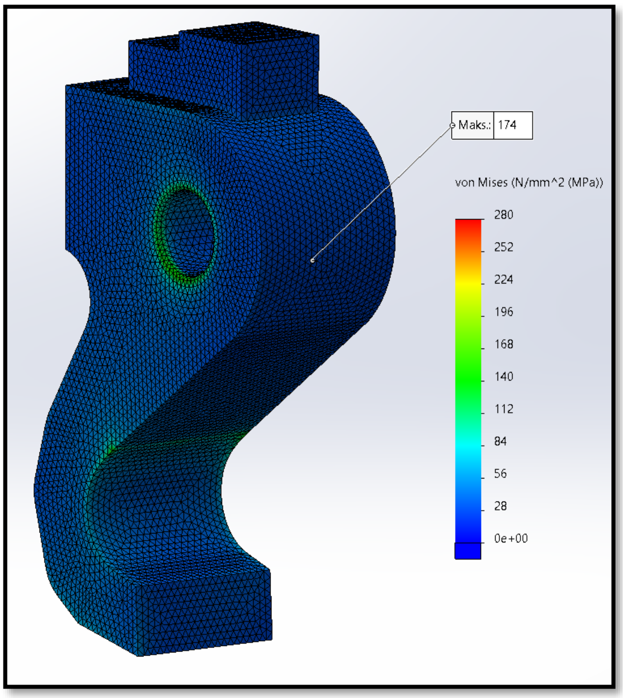
$$\sigma_x, \sigma_y, \sigma_z = Axial\ Stresses$$

3. RESULTS AND DISCUSSION

As a result of the structural analysis of two locking mechanisms with the same boundary conditions, the maximum conjugate stress (Von Mises) and displacement (mm) values were analyzed. Fig. 6 shows the stress distribution for the butterfly and hook lock mechanisms.



(a)

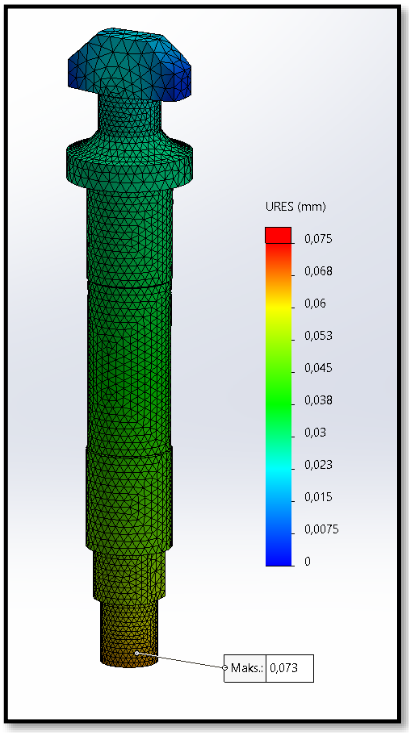


(b)

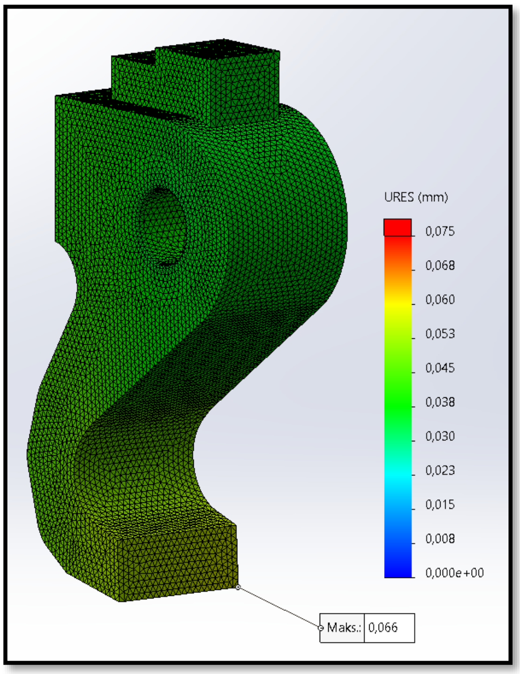
Fig. 6. a) Butterfly lock mechanism and b) Hook lock mechanism stress distribution

The maximum conjugate stress values for the butterfly and hook lock mechanisms design were 266 MPa and 174 MPa, respectively, (Fig. 6a and 6b).

Fig. 7 shows the displacement distribution found for the butterfly and hook lock mechanisms.



(a)



(b)

Fig. 7. Displacement distribution of a) Butterfly lock mechanism and b) hook lock mechanism

The maximum displacement values for the design of the butterfly and hook lock mechanisms were found to be 0.073 mm and 0.066 mm, respectively, (Fig. 7a and 7b). The force is transmitted via contact stresses in both the butterfly and the hook mechanisms. However, the force-transmitting surfaces in the butterfly mechanism are smaller than the hook mechanism. Therefore, it is expected that more stress will occur on the butterfly mechanism. On the other hand, the butterfly mechanism is forced in the extension direction, while the hook mechanism is forced in the bending direction. Therefore, it is expected that there will be slight differences in displacement between these two designs. In both designs, the minimum displacement expected from the locking mechanism is because the large displacement prevents the thickness of the baked wafer plates from being homogeneous. Table 3 shows the stress and displacement results for both mechanisms.

Table 3. Analysis result values and rates of change for the design of butterfly lock mechanism and hook lock mechanisms

Lock Type	Maximum Equivalent Stress (MPa)	Maximum Displacement (mm)
Butterfly	266	0.073
Hook	174	0.066
Diff. (%)	34.5	9.5

4. CONCLUSION

The findings and comments resulting from the analysis are summarized below.

- The Von Mises maximum stress value of the hook lock mechanism is 34.5% lower than the Von Mises stress value of the butterfly lock mechanism.
- The maximum displacement of the hook lock mechanism is 9.5% lower than the maximum displacement of the butterfly lock mechanism.
- The total contact area of the butterfly lock mechanism was calculated as 135.66 mm^2 and the total contact area of the hook lock mechanism was calculated as 2247.7 mm^2. It is seen that the total contact area of the butterfly lock mechanism is shallow compared to the hook lock mechanism. For this reason, it is predicted that the stresses on the butterfly lock mechanism will be higher, and the wear caused by the contact operation will be higher.
- In the continuation of this study, the stress values can be reduced by performing analysis under the same loads with different locking mechanism designs with more contact surface area and different engineering materials.

5. ACKNOWLEDGEMENT

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