Finite element analysis of frictional coefficients in press fit pins

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Abstract. The automotive industry places electronic components in vastly different conditions compared to that for residential purposes. Thus, there are certain components that have found an essential use in this industry. One such component is the press fit pin. The press fit pin is seen as an alternative to soldering because it is cheaper to implement and more reliable at times. All technologies however, come with disadvantages. One of the common issues encountered by press fit pins are the excessive stresses on both the pin and the hole during insertion which tend to cause deformation or cracks in the substrate material. Because of this, the main topics of research on press fit pins are most commonly on the insertion forces and retention forces present. These forces occur on the interfaces between the pin and the hole where it is inserted. Therefore, there have been several studies on the friction between the two components. The studies however, only explored the frictional coefficient of their present system which reduces its applicability on other designs. This work seeks to present an in-depth finite element analysis on the effects of varying frictional coefficients would have on the equivalent stress and retention forces present on the press fit pins.

1. Introduction
Electronics are becoming more frequently used in automobiles and other industrial machines. Most components and features of the modern vehicles are controlled by electronic components. Automobiles are mainly used for transportation wherein they undergo many different conditions such as violent weather and rough roads. Because of these, the electronic components within them are also subjected to the same conditions. Components within the engine compartment tended to experience temperatures of 125 °C to -40°C in the winter [1]. These are greatly differed from the normal operating range of conventional household appliances. There are also global movements, such as the Restriction of Hazardous Substances Directive of the European Union, aimed at removing hazardous materials from electronic devices. Due to these, the design of electronic devices has been constantly adapting to the various conditions that they will be subject to. The elimination of lead, which was one of the most used elements in solder, became a priority in the electronics industry. This led to the increase in interest in alternatives to solder [2]. One of the measures to adjust to the conditions is the development of the press fit pin.
Press fit connections are also deemed as the successor of soldering as they also have the added benefit of making the manufacturing processes more reliable. This is because they remove the need for the high temperatures involved in the soldering process. The press fit technology creates connections between components electrically and mechanically through a pin which is inserted through a hole where the elastic deformation between the components holds it in place [3]. There are two main types of press fit pins, the active pin, and the compliant pin. Active pins are usually designed as rigid connectors usually with straight edges to facilitate the insertion. Compliant pins on the other hand, are made to deform when inserted into the hole. The most common pin design is the Eye of Needle (EON) as shown in Figure 1.

![Figure 1. Illustration of an Eye of Needle press fit connector inserted into a hole.](image)

Though this technology could overcome the problems of soldering, excessive deformation sometimes occurs in the assembly which causes failures [4]. To minimize this, there have been numerous studies on the different parameters of the press fit connections such as insertion force, retention force, pull out force, contact force. Majority of the studies on press fit pins are based on physical experiments though several studies have also involved finite element analysis [4-7] to gain a more in-depth view of the system.

The use of press fit connectors in the automotive industry subjects them to high temperatures, vibration, and corrosion. The various aspects of the press fit pin’s performance such as its reliability [7], [8], degradation [3], thermal cycling performance [3-5], frictional performance [2,6,9,10], creep [5], and whisker formation[11-13].

Of the studies on the frictional performance of the press fit pin connectors only one used FEA [6], and they concentrated on determining the actual frictional coefficient of the system. Though it is important to understand the frictional coefficient of exiting systems, this does not give information that could be adapted to other press fit pin designs. The current work seeks to present the effects varying frictional coefficients of press fit pins on the retention force and equivalent stresses for application in future designs.

2. Methods
This study used Finite Element Analysis (FEA) to investigate the effects of varying Coefficients of Friction (COF) on the retention force of EON press fit connectors. This current study chose to use the EON design because it is the most used type of press fit connector. This is also to enable the findings from this study to be more applicable to most of the press fit pins. The FEA software used in this study was ANSYS 2020 R1. The simulations were run on an HP Z4 workstation with a single Intel Xeon Gold 6230 CPU and 128GB of RAM.

FEA is a numerical procedure that divides objects into elements connected by nodes. The elements are commonly in the shape of triangles but may also be composed of other shapes. The number of elements in a simulation varies depending on the size of the object to be analyzed and the resolution needed. These elements and nodes are interconnected in what is called the mesh of the model. A solver would then compute for the values of the parameters of interest of each node of the element. When all the information of the values on each node are combined, they would produce the complete picture of the effects that forces, temperature, gravity, or other conditions have on the object or system. Because of this, FEA is especially suited to investigate the forces and deformation on mechanical systems such as press fit connectors.
The press fit pin is to deform when inserted. This behavior could be defined by the following equation:

\[ \delta = \frac{PL}{AE} \]  

Where \( \delta \) is the deformation, \( P \) is the force acting on the pin, \( L \) is the original length, \( A \) is the area, and \( E \) is for the elastic coefficient.

Another parameter to be analyzed are the stresses created by the contact of the pin to the walls of the hole. This could generally be described by:

\[ \sigma = \frac{F_x}{A} \]  

Where \( \sigma \) is the stress produced and \( F_x \) the force acting on the body.

One of the main parameters to be analyzed in this study is the retention force which is created due to the frictional forces acting on the pin and hole. It is given by:

\[ F_f = F_n \times \mu \]  

Where \( F_f \) is the frictional force, \( F_n \) is the normal force, and \( \mu \) is the COF. It was applied to each element and computer relative to its location on the model. (Comment 1.d.)

This study used the built in ANSYS meshing software to create the mesh of the pin and hole. The sizing of the mesh at the interfaces between the two parts is set at 0.02mm to accurately model the interference between the two which is also set at the same value. The rest of the mesh was automatically generated by the meshing software. The resulting model was comprised of 108,571 elements with
195,720 nodes as seen in Figure 2. The mesh had mostly Tet10 and Hex20 elements. Figure 3 shows the orthogonal quality and skewness of the mesh on the x-axes and the percentage of elements in the y-axis. For the orthogonal quality, the closer its value to one, the better; for the skewness, the closer to zero the better.

![Diagram](image)

**Figure 4.** (a) The initial position of the system; (b) The final position of the system.

Fixed supports were added to the outer sides of the box of the hole to prevent movement. A frictionless support was also added to the faces of the hole near the sharp end of the pin to prevent it from being pulled along with the pin. From its initial position, the pin was displaced 2.75 mm until it was fully out of the box as seen in Figure 4. Frictional contacts were set between the surface of the pin and the inside of the hole. The pin had a length of 4.8 mm and was based on default specifications. In addition, the width of the pin was 1.2 mm, diameter of the hole to be inserted into is 0.96 mm and the sides of the box are 1.5 mm.

The main assumption made in the study was that the pin was already inserted at the start of the analysis and was to be pulled out as seen in Figure 4. The stresses and forces within the system would then be collected then analyzed.

![Diagram](image)

**Figure 5.** Enlarged view of the interference between the press fit pin and the hole.
Press fit connectors are held in place due to the elastic deformation of either the pin or the hole. To account for this in the simulation, the width of the pin was made 0.02mm wider than the radius of the cylindrical hole that it is inserted in as seen in Figure 5. The analysis type used in the simulation was static structural then the simulation was run with two steps. Since it was assumed that the pin was already inserted at the start of the simulation, during the first step, the pin could deform to produce the normal force between it and the hole. During the following step, the pin will be pulled out to determine the retention force. The geometry, materials, and displacement of the pin and hole are held constant while the COF is varied. The values of COF used in the study ranged from 0.2 to 0.4 with intervals of 0.05 for each run for a total of five simulation runs. The values for the frictional coefficient was based on the range of results from the study of Tohmyoh et al. [6]. The maximum stresses occurring on the system would then be recorded. The materials used in the study are summarized in Table 1 and Table 2. It is to be noted that the PCB Substrate material is orthographic thus it has different properties in different directions as seen in Table 2. X, Y, and Z in Table 2 refer to the axes, which define the properties the material has along them. The same applies to XY, YZ, XZ which refer to the planes where the properties are defined. The mesh of both the pin and the hole were made finer only in the areas that are in contact with each other. This is to increase the accuracy of the simulations while minimizing the computational time.

| Table 1. Material properties of Cu and CuSn5. |
|------------------|------------------|
|                  | Hole(Cu)          | Pin(CuSn5)        |
| Young's Modulus  | 40200             | 118000             |
| Poisson's Ratio  | 0.35              | 0.3                |
| Bulk Modulus     | 44667             | 98333              |
| Shear Modulus    | 14889             | 45385              |

| Table 2. Material properties of the PCB substrate. |
|------------------|------------------|------------------|------------------|
|                  | XY               | YZ               | XZ               | X               | Y               | Z               |
| Young's Modulus  | 1700             | 745              | 1700             | 0               | 0               | 0               |
| Poisson's Ratio  | 0.13             | 0.13             | 0.42             | 300             | 300             | 240             |
| Shear Modulus    | 0                | 0                | 0                | 0               | 0               | 0               |

3. Results and Discussion

The five simulation runs approximately ran for 30-40 mins each. The results of the simulation show a relatively large stress on the first COF setting with an equivalent stress of around 48 MPa. The succeeding three COF settings had values close to each other with a trend of increasing retention force. There was another jump in the value of equivalent stress at 0.4 COF. This shows that there is a nonlinear relationship between equivalent stress and COF. The retention force, however, behaves as expected wherein it increases as the COF also increases. Figure 6 shows the COF on the x-axis and the values of equivalent stress and retention force on the y-axis. The visualization allows for analysis of the relationship of the variables used in the system. Table 3 displays the actual values obtained from the simulation. The desirable characteristics for press fit connections are low stresses and high retention forces. As can be seen from the results, the desirable range of COF lies between 0.2 and 0.4.
Table 3. The results of the simulation.

| Coefficient of Friction | Equivalent Stress (MPa) | Retention Force (N) |
|-------------------------|-------------------------|---------------------|
| 0.20                    | 48.07                   | 10.67               |
| 0.25                    | 34.27                   | 13.16               |
| 0.30                    | 34.71                   | 15.58               |
| 0.35                    | 34.80                   | 17.98               |
| 0.40                    | 40.50                   | 20.35               |

The is normally not adjustable variable since it largely depends on the materials used as coatings on the pin and hole. Knowing the desirable COF would however, aid designers during the material selection process since the COF of materials is usually available from suppliers. Apparatus such as that described in [9] would make the determination of COF of materials faster and more efficient. The results of this study could be used in conjunction with the findings from [14] for a complete materials selection process that takes into account friction and the thermomechanical properties in the design of semiconductor devices.

Figure 6. Graph of the relationship between forces and their equivalent stresses

4. Conclusion
The simulation focuses on effects of the coefficient of friction (COF) to the press fit configuration. The simulation results had shown that there is an increasing trend between the COF and the retention force. Based on the data gathered, COF had significantly affected the retention force of the pin, as the COF increases, the resulting retention force also increases. It is also noteworthy that the equivalent stress does not behave linearly with the COF. The change in equivalent stress value for the COF of 0.2 to 0.25 was significantly greater than that of 0.25 to 0.3. Though the change in retention force between the COFs had less variations. A more in-depth simulation will be done to further analyse the trend of the equivalent stress with respect to the COF. Based on the trend obtained from the result, the COF value can be considered as a parameter for the design of a pin in a press fit configuration to increase or decrease the retention force based on the configuration requirements. Future studies will explore the stresses and retention at varying normal forces and COFs. The insertion force will also be investigated. Detailed experimentation and modelling are recommended by the author to further analyse the correlation of different parameters that are related in press fit. These significant findings can aid in the design guidelines of a press fit configuration.
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