Design Optimization of Connector Secondary Latch to Avoid Failure in Automotive Connectors

[1*]Jagadeesh Patil, [2]J Sharana Basavaraja

[1]*Mechanical Department, B.M.S College of Engineering, Bengaluru, India.*
[2]*Mechanical Department, B.M.S College of Engineering, Bengaluru, India.*

---***---

Abstract - *Automotive connectors are essential elements in modern automobiles, ensuring reliable and secure electrical connections for a variety of systems. Among these connectors, miniature connectors with hinged latches play a crucial role in maintaining electrical continuity. The hinge failures and cracks that can appear on these connectors at the hinged junction, however, may affect their function and raise safety issues. This paper presents a comprehensive design optimization approach for the independent secondary lock (ISL) mechanism in automotive connectors. The primary objectives are to minimize von Mises stress and logarithmic strain, which will ultimately reduce the risk that cracks would occur and the hinge will collapse.*

The study involves a comprehensive evaluation of various hinge profiles while keeping material, and operational aspects into unchanged. The mechanical behavior of various hinge configurations is assessed using refined FEA models under accurate loading conditions. The results show that particular hinge profiles exhibit improved stress distribution and strain reduction, significantly reducing the occurrence of crack marks at the hinged joint. Additionally, to ensure the modified hinge profile's improved efficiency in decreasing crack marks, The findings show that cracks has significantly decreased, improving the connections' long-term dependability and durability.

Key Words: Crack Marks, FEA analysis, Hinge profile design, Miniature connector, Design Optimization.

1.INTRODUCTION

Snap fit system requires a lot of effort to design and integrate to improve the functionality and producibility of these critical joints. The focus in snap-fit application has traditionally been on precisely engineering individual features, accounting for elements such as deformable beam diameters and unique locking mechanisms suited to various snap-fit kinds and cross-sectional area. Recent developments, however, have highlighted the significance of a holistic design perspective that seamlessly integrates both the conceptual and detailed design stages. The dimensions of the deflection mechanisms are determined, and retention elements are incorporated into the locking system, simultaneously during the detailed design phases. Drawing on the wide body of literature on general snap-fit designs, especially for cantilever snap fit joints, is often needed for this.

An independent secondary lock (ISL) is a type of locking mechanism to ensure a secure and reliable connection between two components. It is called "independent" because it is separate from the primary locking mechanism and provides an additional layer of security. We can see whitening markings at the hinge region of this specific connector when ISL closes as it advances from the pre-lock to final lock positions.

2.0 MATERIALS AND METHODOLOGY

2.1 MATERIALS:

The research work involves usage of miniature Connector which are made up of a special type of Polymer named PBT fiber glass reinforced 6% (Polybutylene terephthalate), which has an excellent balance of mechanical properties and processability. It possesses high strength, better dimensional stability and low creep properties. PBT is not easy to decompose under water at normal temperature. Also, it has excellent insulation properties which makes it ideal material for electrical and electronics parts. And due to fast crystallization speed and better fluidity the mold temperature of PBT is lower than the most engineering plastics.

2.2 METHODOLOGY:

Identify key parameters and part of latch that can be modified to optimize the design of ISL

↓

Using Hyper Mesh software to mesh the Connector with integrated latch

↓

Simulate the snap-fit operation of the ISL using Abaqus for the existing design and check for ISL failure.

↓

Propose multiple optimized ISL profile designs to overcome the failure. and perform the simulation on the optimizes design using Hypermesh & Abaqus.

↓

Summarize the findings, draw conclusions and recommend the manufacturing industry on the optimal design of latch in accordance with USCAR regulations.

3.0 MATERIAL PROPERTIES

Description	Type/ value
Material	PA66 (Nylon)
Nominal elongation	4%
Density in Kg/m3	1.36E-9
Poisson's ratio	0.35
Yield strength in M Pa	59 M Pa

4.0 MESHING

To improve simulation accuracy, the connector housing and latch were meshed using second-order tetrahedral elements. The mesh was improved in critical areas such contact areas, stress concentration areas, and areas of relevance to maximize computational efficiency.

A 2D fine meshing was used when meshing the latch component, resulting in a denser grid of mesh elements with an element size of 0.1mm. This method focused on specific geometry areas that needed closer examination, like the stress concentration at the hinge region and the contact surface of the latch. This approach represents local behaviors and stress changes more accurately than a homogeneous mesh because it distributes computing resources to where they are most needed. The geometry's complexity, as well as the expected stress distribution and strain relaxation, provide as a guidance in choosing these particular regions. The simulation can better capture intricate behaviors that would be missed with a coarser mesh, which is set at 0.8mm in other locations, by using a finer mesh in certain areas.

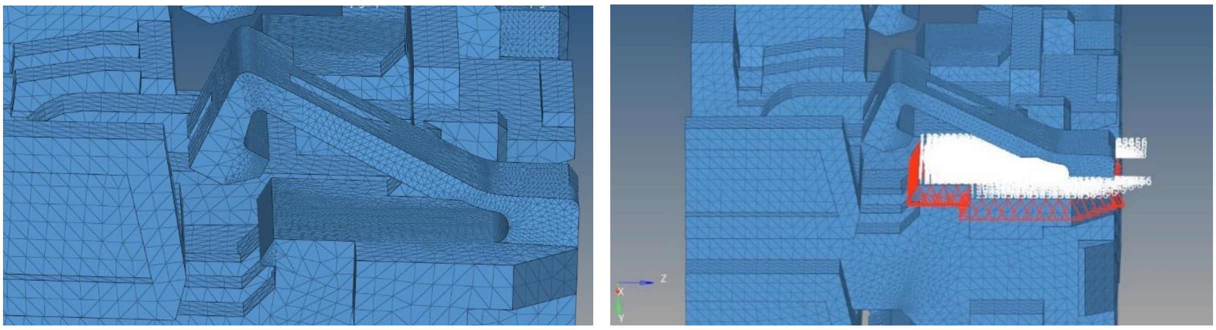

Fig 1: Connector latch Meshing

To replicate real world conditions, the mentioned nodes of the connector's housing are fixed as shown in above figure. This simulates the testing procedure, and how the housing is securely held. The top surface nodes of the latch component are fixed in Z direction as shown above to represent the constraints during operation

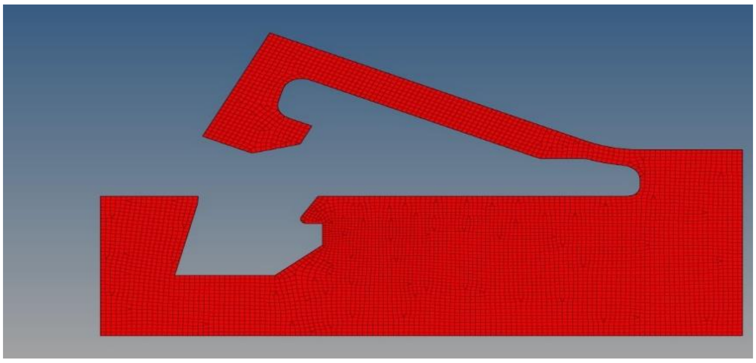

Fig. 2: 2D latch Meshing.

A service tool or rigid plate is used to provide force during the connector assembly procedure in a realistic testing setting. This plate is subjected to displacement in the Y-direction in order to replicate the latch component contacting with the connector housing. The latch is given a displacement of 2.5 mm from its pre-lock position to its final lock position in this instance.

In this analysis, a contact friction coefficient of 0.1 is introduced to account for interactions between housing and the latch. This methodical approach is anticipated to significantly reduce the computational overheads associated with pre-processing and post-processing within the software, enhancing efficiency and overall optimization of the automobile connector assembly design in terms of efficient ISL engaging process.

5.0 SIMULATION STUDY FOR EXISTING DESIGN

FEA simulations are done by keeping the same material and only focusing on the different latch profiles in the analysis. In the first iteration, the simulation is done using 3D model Fig 3 shows the logarithmic strain distribution and Von-mises stress distribution in the connector. As the latch approaches the final lock position maximum logarithmic strain was observed at the hinge region which leads to crack marks in the hinge region.

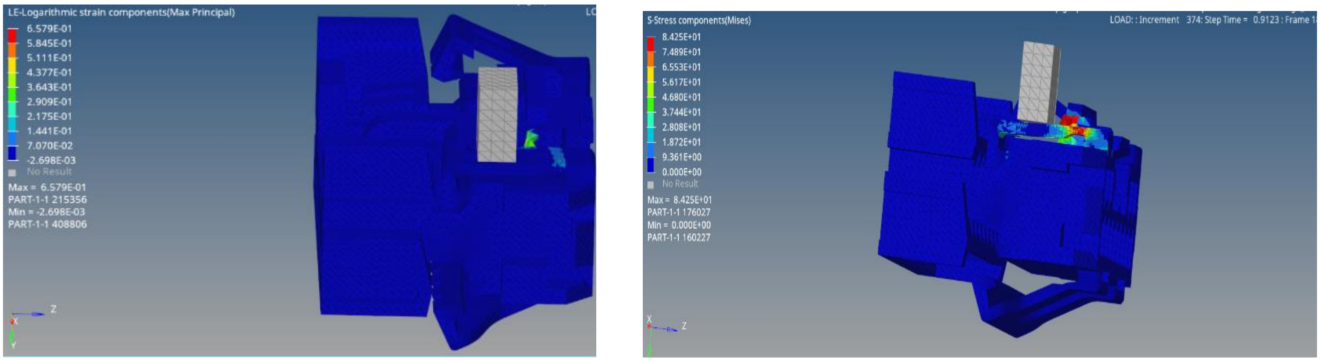

Fig. 3: 3D latch stress and strain overview.

To reduce the computational time, 2D section was considered for the simulation. Fig 4.1 shows 2D latch design. where reduction in the width of latch's slant edge is very less which further indicates that hinge region doesn't have sufficient area for the stress distribution and hence causing higher stress values in the hinge region.

6.0 OPTIMIZED DESIGN OF THE CONNECTOR LATCH

One of the design constraints was to use the same material and focusing only on the different latch profiles in the analysis. All the required dimensional changes were made using NX Siemens software. Notably, the latches were designed in such a way that, this alteration aimed to optimize and eliminate crack marks that formed on the hinge region resulting in whitening marks on the hinge region in Connector. By proposing new latch profiles at the hinge region design was optimized and results aimed to have better stress relaxation and decreased logarithmic strain values. Furthermore, the latch engaging force was measured when it reaches final lock position in the housing, and it made sure this latch engaging force values meet the acceptance criteria as per the United States council of automotives research standard.

7.0 D OPTIMIZED LATCH DESIGNS:

As baseline design has less reduction in the width of latch's slant edge, in option 2 it was optimized and made sure that specified dimension at the hinge region is sufficient for the stress to distribute at the hinge region. In further designs in option 3 profile of hinge is made more likely circular in this design with proper blend radius making the latch deforming within limit. Which makes option 3 design better compared to all other designs and expecting more reduced logarithmic strain values and better stress relaxation in the hinge region. Option 4 design has different profile at the hinge region compared to all other previous latch designs, expecting a better stress relaxation with much reduced logarithmic strain values at hinge region.

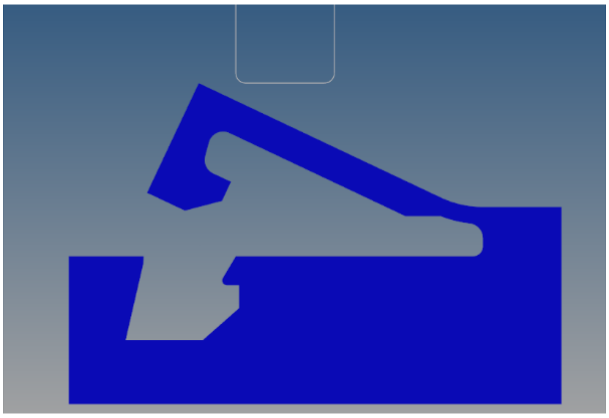

Fig a: (Option 1)

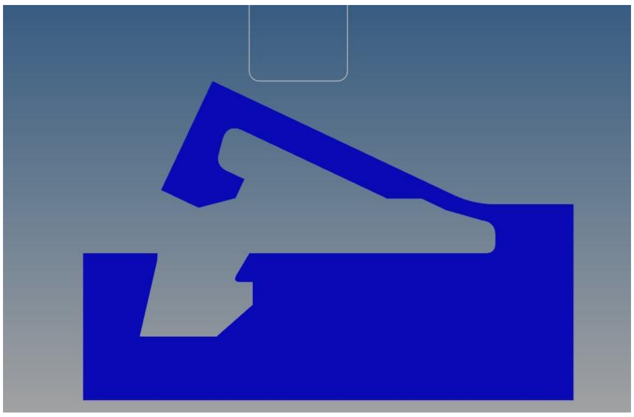

Fig b: (Option 2)

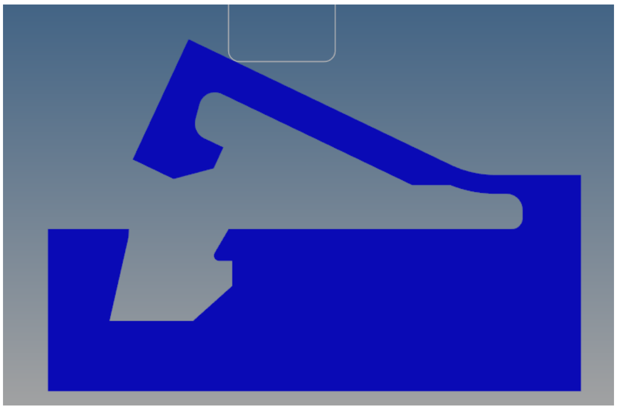

Fig c: (Option 3)

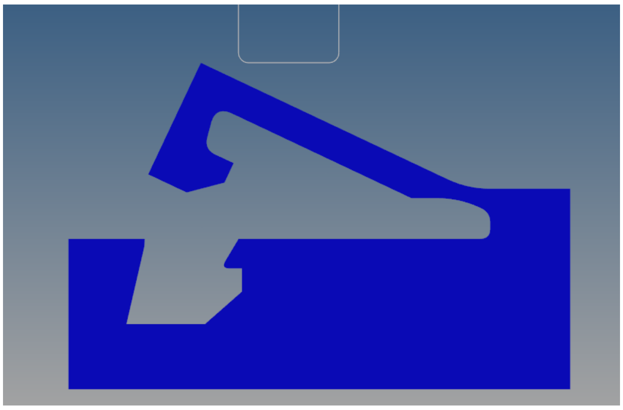

Fig d: (Option 4)

Fig 4: 2D latch design.

8.0 OPTIMIZED DESIGN RESULTS:

The initial design of the connector latch was having crack marks at the hinge region as latch moves from its pre-lock position to final lock position. Analysis results shows that when latch reaches its final lock position both the stress and logarithmic strain values crosses the critical values of the material. And it is found that these exceeded logarithmic strain values are causing crack marks at the hinge region. Hence the study with different latch profile designs were considered and finally found that Option 3 was better among all the optimized designs as it significantly reduces the logarithmic strain values at the hinge region and eliminating the risk of having crack marks.

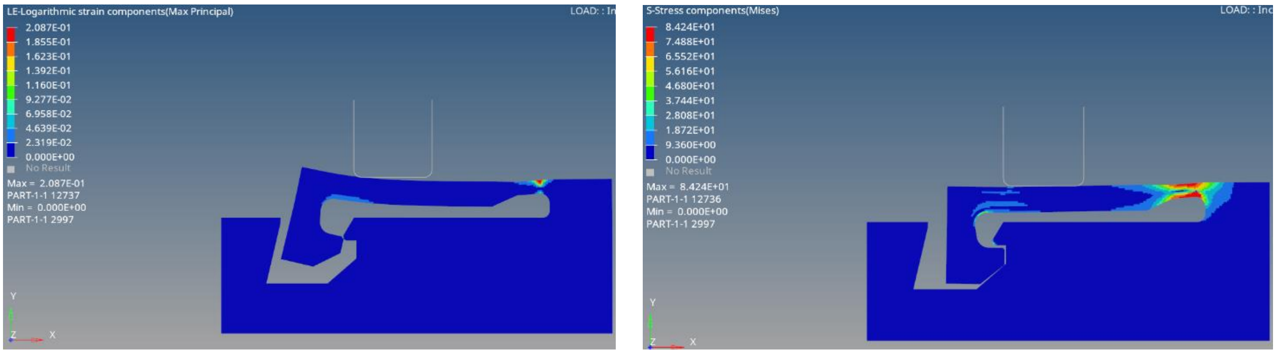

Fig a: 2D latch design (Option 1) results.

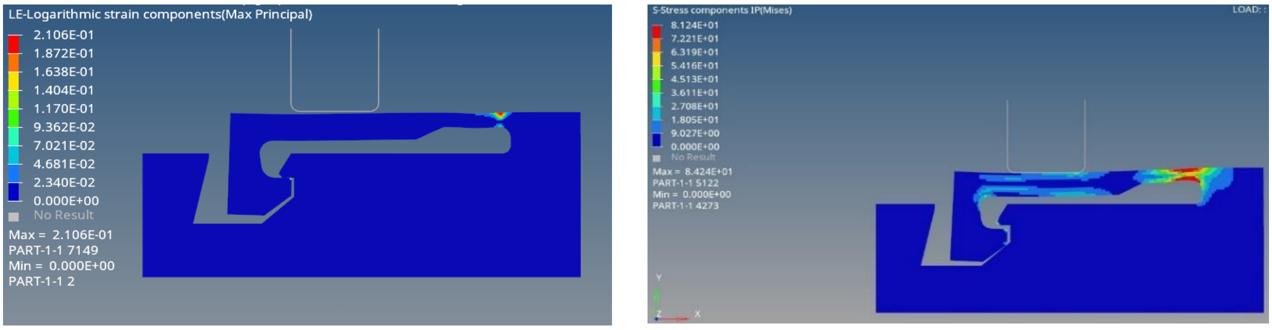

Fig b: 2D latch design (Option 2) results.

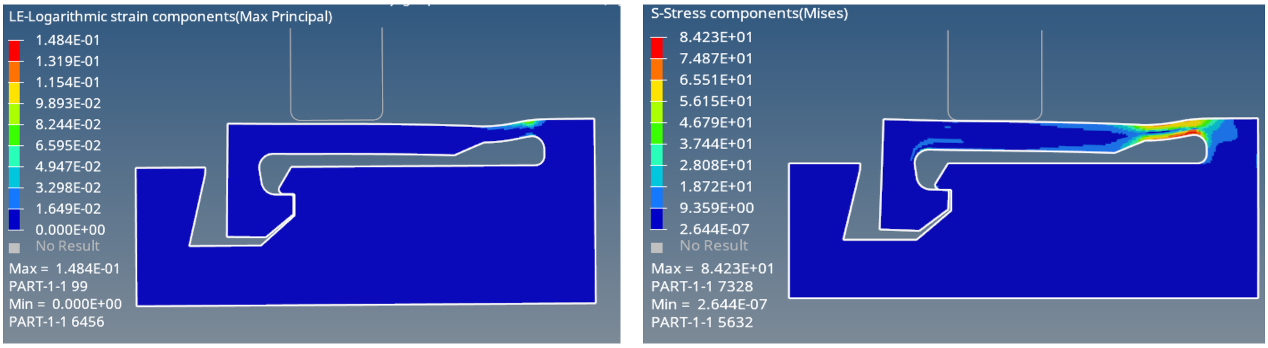

Fig c: 2D latch design (Option 3) results.

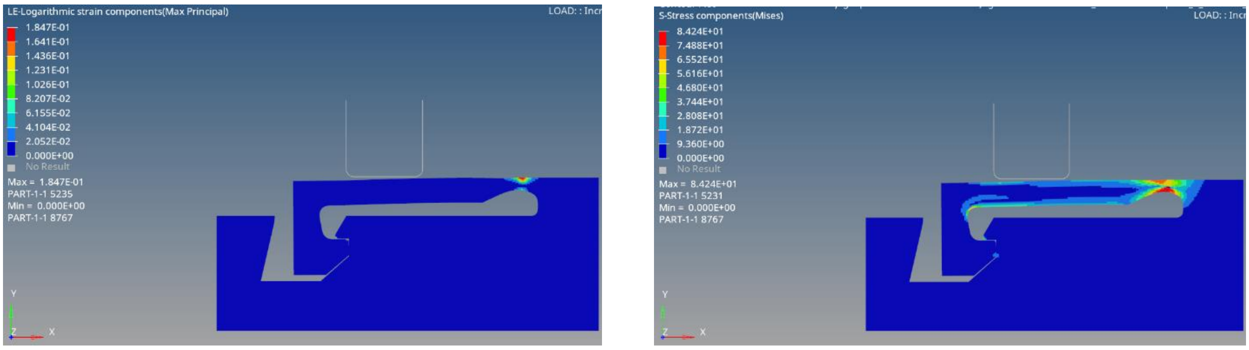

Fig d: 2D latch design (Option 4) results.

9.0 TESTING & CORRELATION

Consider 10 connectors and do inspection with the naked eyes for pretest inspection. secure the connector housing in an appropriate fixture. Using appropriate push rod, push the latch from pre-lock to final lock at a uniform rate of 50 mm/min. Record the maximum force. The Fig below shows the force testing equipment with the connector is held.

Figure 6: Force testing equipment

Component - loose piece latch, engage force was done to validate the accuracy and reliability of the simulation results by comparing them to real word data. Box plots were plotted using Minitab software to know the spread of the data and to identify the outliers due to any unavoidable circumstance.

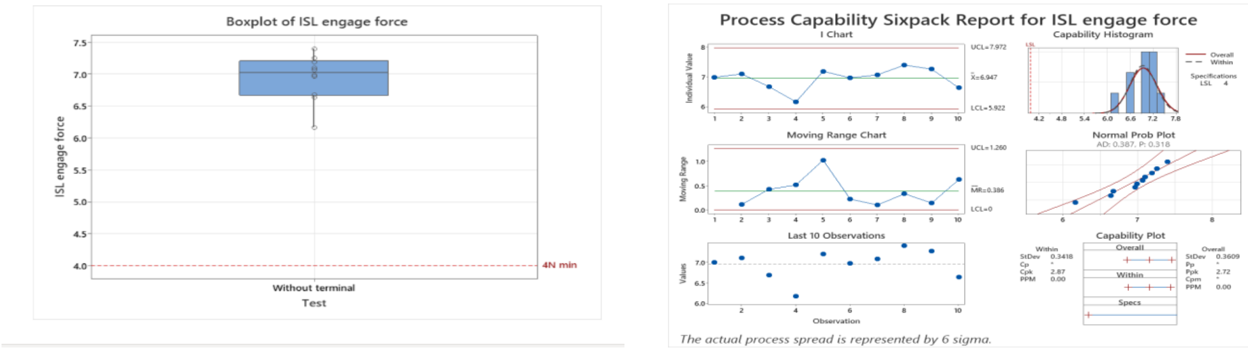

Fig 7: Boxplots & Capability plots for ISL engage force values

The results of the test verified that the component - loose piece latch, engage force test results met the acceptance criteria of USCAR standards for which we were validating the connector. And process capability sixpack report shows that PPM values are equals to zero. Which indicates that there are zero failure parts per million.

10.0 CONCLUSION

- The investigation resulted in a better latch profile design that exhibited a noticeable reduction in the logarithmic strain value as the latch approached its final lock position.
- The decreased logarithmic strain value that was seen in the simulated testing is evidence that the design optimization efforts were successful. The modified design enhanced the integrity of the latch contact in addition to reducing the strain values. This is necessary to maintain consistent and reliable electrical connections and to keep the terminals in their proper locations in many automotive systems, which enhances the performance and safety of the vehicle.
- The study highlighted the importance of approaching automotive engineering from various disciplinary angles. The collaboration of mechanical design, material science, and electrical engineering resulted to a comprehensive and effective design solution.
- The accuracy and usefulness of the simulation tools were proven through the validation process, which comprised comparing simulation results to actual measurements. This validated both the design optimization and the validity of the simulation methodologies.

11.0 LIMITATIONS AND COST IMPLIPICATIONS

- These connectors with improvised ISL design can be used in the applications where only 10 engage- disengage cycles of ISL are limited.
- These new ISL design may pose challenges for manufacturing team to mold it from 2-piece injection molding process.
- New mold inserts have to be used to produce the connectors with the optimized ISL design. Meanwhile the same injection molding setup can accommodate these design changes, the cost of production should be less in long term production.

12.0 REFERENCES

[1] Rajini Rohith, Shivakumar S, "Design Optimization of Electrical Connector Assembly using FEA", Journal of mines, metals and fuels, ICRDME 2022 A1 Oct. 15, 2022.

[2] Ying Li, Fulong Zhu, "Analysis of insertion force of electric connector based on FEM", IEEE 21st International Symposium on the Physical and Failure Analysis of Integrated Circuits (IPFA), 2014 IEEE.

[3] Anthony, C.; Cheung, W.M. "Cost evaluation in design for end-of-Life of automotive components". International Research Journal of Engineering and Technology, Volume:06, Issue: June 2019.

[4] ZHOU Yi-lin, ZENG Ning et Al. "Failure analysis of a kind of low power connector", Journal of Zhejiang University SCIENCE A, revision accepted Jan. 5, 2007

[5] M. Leidner, H. Schmidt, M. Myers, and H.F. Schlaak, “A new simulation approach to characterizing the mechanical and electrical qualities of a connector contact.” The European Physical Journal Applied Physics: 11 Issue: 26 January 2010

[6] Liu Bong-yang, “The Characteristic Research of Contact Insertion and Separation Force in Connector.” Thirty-Sixth IEEE Conference on Electrical Contacts, and the Fifteenth International Conference on Electrical Contacts, 20-24 August 2020.

[7] Dr. D Y Patil, “Design optimization of snap fit feature of lock plate to reduce its installation force by using DOE Methodology.” International Research Journal of Engineering and Technology, Volume:06, Issue: June 2019.

[8] S. J. Niranjanaa*, S. S. Kubsadb, S. Manjunathac, Y. Nagarajd, I. Bhavie, B. M. Angadie, A. J. Chamkhaf, M. B. Vanarottig,” Experimental Investigation and Numerical Simulation of Air Circulation in a Non-AC Bus Coach System”. International Journal of Engineering. IJE Transactions C: Aspects Vol. 35, No. 03, (March 2022) 572-579.

[9] Shravanabelagola Jinachandra N, Sadashivappa Kubsad S, Sarpabhushana M, Siddaramaiah S, Rajashekaraiah T. Modeling and computational fluid dynamic analysis on a non-AC bus coach system. Heat Transfer. 2020; 1– 8.