Investigation on Optimization of Baking in Sole Bonding Process

Dyi-Cheng Chen, Hua-Wei Jin, and Jhang-Zong Su

Department of Industrial Education and Technology, National Changhua University of Education, No.1, Jinde Rd., Changhua City, Changhua County 50007, Taiwan
E-mail: dchen@cc.ncue.edu.tw

Abstract. Nowadays, Taiwan's footwear industry has become more computerized and automated, but there are still places in the manufacturing process that can be optimized. In the general shoe bonding process, baking requires very high power and a long time. This Investigation used Solidworks to build a common shoe model, and used Solidworks simulation and other CAE software to discuss the baking soles and achieve the soles. The heat required for the baking process to optimize the parameters of temperature and time is achieved through the TRIZ theory to optimize parameters such as power and time required for the baking process, it can be heated by asymmetric heating to obtain a surface with relatively uniform heating to obtain a solution that effectively reduces the production cost in the process. It is found that when the heating source is separated by 40 mm, a surface with relatively uniform heat can be obtained.

1. Introduction

Although there are many computer-aided equipment and automated machinery, not only can the shoemaking time be greatly shortened, but also the customized shoemaking process can be developed. However, the materials of the shoes are very diverse, and because of the development of customization, each pair of shoes, the size and thickness of the outsole and the midsole are not the same. At this time, it is difficult to control the temperature and time when the midsole and the outsole are bonded. The problem in this aspect is that the engineer or the field master uses the trial and error method. The test is constantly repeating to find the right temperature and time to solve the problem, so it will waste a considerable amount of time in this part of the test, but also many resources are not easy to reduce the cost.

Common materials for the sole are rubber (RUBBER), thermoplastic rubber (TPR), ethylene (EVA), and synthetic resin (PVC). In 2005, Pern and Jorgensen [1] studied adhesion of EVA laminates to glass substrates and enhanced the adhesion strength of EVA. In 2010, Saboo [2] studied bonding strength of EVA modified mortar was tested. In 2011, Ethylene/Vinyl Acetate Copolymers (EVA) for encapsulation of photovoltaic modules were investigated by the thermal analysis methods of Differential Scanning Calorimetry (DSC) and Dynamic Mechanical Analysis (DMA) in the temperature range from −150 °C to 200 °C [3].

In 2012, Alsaed and Jalham [4] investigated polyvinyl butyral (PVB) and vinyl acetate (EVA) as bonding materials on laminated glass on mechanical behaviour. In 2013, Polansky et al. [5] studied the mechanical behaviour and the thermal stability of an encapsulant based on ethylene-vinyl acetate (EVA). The EVA properties were verified at temperatures ranging from −70 °C to 500 °C. In 2016, Saboo and Kumar [6] studied obtaining the optimum blending temperature, time and shear rate for EVA co-polymer.
2. Research method and procedures

2.1. Research method
In order to achieve the purpose of research, this study uses computer-aided engineering analysis (CAE) technology to simulate the situation when the outsole and midsole of the shoes are bonded, and then use TRIZ theory to find out ways to improve the production capacity of the footwear industry, and to do a series of simulation analysis and optimization of experiments and parameters.

2.2. Research procedures
First set the research process to use the relevant parameters, and then use the heat transfer related formula to calculate the time required for the soles to be baked, so that the bonding surfaces reach the specified temperature, and finally use the Solidworks drawing software to draw the outsole and the midsole model, and open the simulation analysis module of Solidworks to simulate the state of the shoe outsole and midsole heating process, verify that the time required for heat to reach the specified temperature is consistent, and then use TRIZ theory to find a solution to the problem.

2.3. Parameter setting
In order to make the results close to the needs of the site, this study investigated the marketed machines and adhesives on the market, and set parameters that meet the site requirements showing Table 1 for analysis.

| Item                                      | value                        |
|-------------------------------------------|------------------------------|
| The size of the baking machine            | 4500*760*730mm               |
| Baking machine thermal power              | 20kw                         |
| Number of soles placed in the baking machine | 150 piece                   |
| Average maximum thermal power per shoe sole | 133w/piece                 |
| Hot melt adhesive working temperature     | 175°C                        |
| Sole size                                 | 37                           |
| Room temperature                         | 27°C                         |
| Midsole material                          | EVA                          |
| Outsole material                          | TPR                          |

2.4. Calculation of heat transfer
Heat transfer is the process of transferring heat from high temperature to low temperature. There are three ways of heat transfer [7]:

2.5. Heat conduction
It is the process of transferring heat from high temperature to low temperature. It is the result of the vibration energy transmitted by one molecule to another. Formula:

\[
T = \mu [\Delta v + (\nabla v)^T] - \rho I \tag{1}
\]

\[
q_h = -k \nabla T \tag{2}
\]
2.6. Thermal convection

It refers to the relative displacement between various parts of the fluid caused by the movement of the fluid, and the heat transfer process caused by the mixing of the hot and cold fluids. Average convection formula:

\[ q = h \bar{A} (T_s - T_\infty) \]  

(3)

2.7. Thermal radiation

It radiates heat directly through electromagnetic radiation. The conduction speed depends on the absolute temperature of the heat source, and the higher the temperature, the stronger the radiation. Formula:

\[ P_{\text{rad}} = \epsilon \sigma T^4 \]  

(4)

The unit of Heat Transfer Coefficient \((k)\) is \(\text{W/m.K}\), and the thermal conductivity formula is \(k = (Q/t) \times (A*T)\), which is used to measure the heat energy that can be transmitted per unit time [8]. Using the formula to calculate the temperature of the sole at room temperature after baking in a 20kw oven, how long does it take to make the bonding surface reach 175 °C.

2.8. Computer aided design (CAD) software

CAD (Computer Aided Design) refers to the use of computers for design and drawing, that is, the use of computer power to design products. Therefore, CAD is an important technology in automation, affecting industrial productivity and quality. The introduction of this technology enables people in related industries to predict and verify the design's performance on the computer in advance, reduce the cost and time-consuming waste of actual trial and error on the spot, and point out the potential of design and production in a scientific way. Problem.

SolidWorks software is often used in small and medium-sized product development, with strong features, good compatibility, and easy access to the interface. It is used for exterior design, mechanism design, drawing engineering drawings, and structural analysis. It is a software that can combine design end and production end. Software usage is the most powerful indicator of software functionality, user satisfaction, and future viability. SolidWorks has a high market share in the design and manufacturing of mechanical equipment.

2.9. Process of bonding the outsole and midsole of the shoe

The final procedure for making shoes is to glue the outsole and the midsole in a glued manner. Glue the already produced outsole and midsole by spraying or rolling hot melt adhesive. After baking, the outsole and the midsole can be aligned and pressed together to complete the outsole. Bonding action is with the midsole. Common bonding methods are cast rubber (C-PUR) and thermoplastic (T-PUR). Casting gluelinear liquid polymer is synthesized by a two-step or one-step method using a compounding agent such as a polyhydric alcohol, an isocyanate or a chain extender, and is poured into a mold during processing, and heated and matured to be converted into a rubbery shape having a certain network structure solid. This method has many advantages and is developing at a faster rate. Thermoplastic type-the reaction of a polyol and an isocyanate to form a linear polymer, processed into a granular solid, and thermoplastic. Direct production using thermoplastic processing equipment and work procedures finished product. This method is the fastest growing in polyurethane rubber. The disadvantages of this type of rubber are poor oil resistance and heat resistance, and mechanical properties are inferior to C-PUR. Characteristics of urethane rubber included strong anti-wear performance, excellent mechanical and mechanical properties, large hardness range, wide modulus range, good oil and low temperature resistance, excellent radiation and ozone resistance.
2.10. Material of the sole
The sole is the core of the shoe, the sole will directly affect the ability of the shoe, the sole of different materials will have different friction coefficient, hardness, weight, durability and so on. The sole is the only part of the whole shoe that will directly touch the ground. In different occasions and different grounds, it is necessary to match the sole of the material to fully realize the ability of the scorpion. Common materials are:

2.10.1. Rubber
This type of outsole material has excellent anti-slip properties and used to be one of the most commonly used materials for special shoes such as rock climbing shoes. The rubber is divided into natural and synthetic, and the supply of natural rubber is not enough for the shoe factory, so the synthetic rubber is the main. The nature of rubber is wear resistance, good elasticity, heavy weight and high cost. Most of today's shoes use such materials for outsole production. In terms of environmental protection, rubber finished materials have various recycling technologies, such as grinding powder into a part of the rubber sole, which is a bit like the concept of recycled paper pulp. Many brand manufacturers specify certain types of shoes to be filled with a certain proportion. Recycling rubber, in addition to reducing the cost of shoe factories, also contributes to environmental protection.

2.10.2 Thermoplastic rubber (TPR)
The full name of TPR is Thermo, Plastic and Rubber to be a thermoplastic composite material with soft touch and adjustable physical properties and hardness. It also reduces production costs. It has both the easy processing properties of thermoplastics and the characteristics of thermosetting rubber and is non-toxic. It is one of the trend materials that save energy and respond to green environmental protection. The resilience, wear resistance, slip resistance and shock absorption of thermoplastic rubber are better than those of ordinary rubber. Therefore, if it is superior to general rubber in terms of comfort, the disadvantage is that the material is inherently stretched and resistant to fatigue. It is not as good as ordinary rubber.

2.10.3 Ethylene (EVA)
It has good flexibility, rubber-like elasticity, and good flexibility at low temperatures. The material itself has high transparency, good surface gloss, good chemical stability, high antioxidant strength, and is as non-toxic as TPR. Because of its light weight, it is the largest amount of material used in sports shoes and casual shoes. Its slip resistance, abrasion resistance and weather resistance can be improved by adding modifiers or other polymer materials.

2.10.4. Synthetic resin (PVC)
It has the advantages of other plastic materials, and it is quite excellent in processing and plasticity. In addition, it is very popular because of its low price, and the production of soles is ecologically friendly. The problem is now rarely used. PVC is generally directly injected into the factory. The texture can be adjusted by pre-injection molding. It can be hard or soft, but the sole of PVC usually has a bit odor and is not popular with consumers.

2.11. Theory of inventive problem solving, TRIZ
TRIZ is derived from the systematic innovation and practice of the Soviet inventor Genrich Altshuller's research on 200,000 patents to solve problems. Emphasis on invention or innovation can be carried out according to certain procedures and steps, rather than just random or imaginative brain stimulation, that is, extracting the principles invented by the predecessors and summarizing them into general rules, thinking direction for solving problems later.

3. Results and discussions
Take the simple size of the store as the object, measure the size of each size of the foot, and complete the model of the outsole and midsole showing Fig. 1, and use Solidworks 2016, the simulation
analysis module simulates the situation when the outsole and the midsole of the shoe are bonded showing Fig. 2, and the entire bonding surface must reach the working temperature (175 °C) or more. The simulation results show that the center temperature of the outsole and the midsole is 271°C, and the boundary temperature is 176°C showing Fig. 3. The temperature difference between the center and the boundary is 95 °C, and the temperature difference is quite large. Heating the boundary temperature above the operating temperature (175°C) must be baked at a heat power of 57 W for 20 seconds.

Figure 1. Model of shoe midsole.

Figure 2. Heat transfer simulation of shoe midsole.

Figure 3. Outsole temperature distribution.

Modify the heating method of the outsole and the midsole, Fig. 4 shows the original heating method, Fig. 5 shows the improved heating method to modify the problem of uneven heating to shorten the baking time and increased bond strength. Fig. 6 shows the results of the modified simulated baking. After modifying the heating mode, the center temperature was 210°C and the boundary temperature was 177°C showing Fig. 7. The temperature difference between the center and the boundary was 33°C.
And use the optimized design function of Solidworks soft body to find the most suitable parameters such as baking temperature and time in Table 2.

**Figure 4.** Original heating method.

**Figure 4.** Improved heating method.

**Figure 5.** Mid-floor optimized heat transfer analysis.
Fig. 6. Improved shoe outsole temperature distribution.

Table 2. Optimized design experiment.

| Case | Material | Thermal power (w) | Heating method | X value | Maximum temperature (°C) | Minimum temperature (°C) | Temperature difference (°C) |
|------|----------|------------------|----------------|---------|--------------------------|--------------------------|-----------------------------|
| Case 1 | EVA 500 | original         | 0              | 381     | 108                      | 273                      |
| Case 2 | EVA 500 | Improvement      | 10             | 337     | 108                      | 229                      |
| Case 3 | EVA 500 | Improvement      | 20             | 333     | 143                      | 190                      |
| Case 4 | EVA 500 | Improvement      | 30             | 219     | 147                      | 72                       |
| Case 5 | EVA 500 | Improvement      | 40             | 163     | 133                      | 30                       |
| Case 6 | EVA 500 | Improvement      | 50             | 198     | 144                      | 54                       |
| Case 7 | EVA 500 | Improvement      | 60             | 183     | 137                      | 46                       |

Fig. 8 shows the line graph drawn by the temperature difference of each item in Table 2, when the X value is equal to 40, the obtained temperature difference is the smallest, and a surface having a relatively uniform heat can be obtained.

Fig. 7. Temperature difference line chart.

4. Conclusions
This Investigation used Solidworks to build a common shoe model, and used Solidworks simulation and other CAE software to discuss the baking soles and achieve the soles. From this simulation
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analysis are found: In order to solve the problem of uneven heating of the sole, it is possible to perform heating by means of asymmetrical heating, and it is found that when the heating source is separated by 40 mm, a surface with relatively uniform heat and increased bond strength can be obtained.

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5. References
[1] F.J. Pern, G.J. Jorgensen, Enhanced adhesion of EVA laminates to primed glass substrates subjected to damp heat exposure, Conference Paper in Conference Record of the IEEE Photovoltaic Specialists Conference, 1, 1-7 (2005)
[2] N. Saboo, P. Kumar, Effect of curing regime on bonding strength of EVA modified mortar to tile, Journal of Wuhan University of Technology-Mater. Sci. Ed. 25, Issue 2, 346-348 (2010)
[3] W. Stark, M. Jaunich, Investigation of ethylene/vinyl acetate copolymer (EVA) by thermal analysis DSC and DMA, Polymer Testing, 30, 236-242 (2011)
[4] O. Alsaed, Issam S. Jalham, Polyvinyl Butyral (PVB) and Ethyl Vinyl Acetate (EVA) as a binding material for laminated glass, JJME, 6, 127-133 (2012)
[5] R. Polansky, M. Pinkerova, M. Bartuňkova, P. Prosr, The Journal of Slovak University of Technology, 64, 361-365 (2013)
[6] N. Saboo, P. Kumar, Optimum blending requirements for EVA modified binder, Transportation Research Procedia, 17, 98-106 (2016)
[7] D.K. Nguyen and J.Y. San, Heat transfer and energy analysis of a spiral heat exchanger, Heat Transfer Engineering, 37, 1013-1026 (2016)
[8] B.W. Li and Z.R. Chang, Comparisons of solving procedures and computation time for fast cosine transformation and matrix multiplication transformation in spectral methods application, Numerical Heat Transfer, Part A: Applications, 70, 384-398, (2016)