VIET NAM NATIONAL UNIVERSITY
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SOCIALIST REPUBLIC OF VIETNAM
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DISSERTATION INFORMATION

Dissertation title:	**EFFECT OF WELDING PROCESS PARAMETERS ON ULTRASONIC WELDING QUALITY FOR NON-WOVEN FABRICS.**
Major:	**MECHANICAL ENGINEERING**
Major code:	**62.52.01.03**
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ABSTRACT

Chapter 1: Overview

This chapter presents the urgency and reasons for choosing the research topic of ultrasonic welding method and the effect of process parameters on the ultrasonic welding process.

The research objectives of the dissertation include studying the theoretical basis of the ultrasonic welding process; designing and manufacturing a 20-kHz ultrasonic welding horn; experimenting ultrasonic welding on non-woven fabrics; analysing the weld joint quality by changing process parameters; optimizing major process parameters using the Taguchi method combined with the Central Composite Face Centered (FCCCD) method.

The research content of the dissertation includes: a survey of ultrasonic welding applications applied to thermoplastics, non-woven fabrics; studying the theoretical basis of ultrasonic welding, thermoplastic materials; researching, designing and manufacturing axial and radial ultrasonic welding horns; optimizing major process parameters using the Taguchi method combined with the FCCCD method to determine the appropriate tensile strength as required.

The dissertation also presents the thermoplastics and the weldability of thermoplastics, the parameters of the materials affecting the welding process. Particularly, for PP plastic, if the welding frequency is 20 kHz, the recommended welding amplitude is from 38 µm.

The different thermoplastic welding methods currently being use are also briefly presented in principle, and the advantages and disadvantages are briefly analyzed. For thin film materials, ultrasonic welding is the fastest and most effective method.

In addition, the dissertation also summarizes the overview of domestic and foreign researches on the ultrasonic welding method, evaluation and analysis of research trends on ultrasonic welding for thermoplastic materials.

Chapter 2: Theoretical Basis and Design of Ultrasonic Thermoplastic Welding

Chapter 2 presents the theoretical basis of the ultrasonic welding method, which includes: the ultrasonic welding principle, the ultrasonic welding source (converts the current with frequency from 50 Hz to current with frequency of 20 kHz), the converter from electric vibration to electric vibration, the vibration amplifier which doubles the initial amplitude of about 22 µm, the calculation of the design of ultrasonic welding horn, and the energy direction zone for the line ultrasonic welding.

Chapter 2 also introduces the process parameters of the ultrasonic welding process, classifies ultrasonic welding methods such as: far welding - near welding, continuous welding - intermittent welding, etc.

In addition, thermoplastic materials have also been presented in the dissertation with specific properties and characteristics of thermoplastics such as: viscoelasticity, structure, etc.

The material for making an ultrasonic welding horn for non-woven fabrics is selected as 7075 aluminum alloy, along with details of the design process of a wide-plate welding horn (the type of horn serving the intermittent welding process) for welding non-woven materials .

The design process of ultrasonic welding horn analysis from the preliminary design on CARD software to simulation and calculation of the operation process on Abaqus software has been detailed. A welding anvil to shape welding seams with different types has also been calculated, designed and manufactured.

Chapter 3: Research Objects and Methods

Chapter 3 focuses on the research on nonwoven materials (specifically, PP nonwoven fabric with 70 GSM), while the production process of nonwoven fabric by injection horning technology and methods for testing the durability of nonwovens has been studied. In addition to the normal failure patterns of nonwovens, test standards for nonwovens have also been presented.

Using experimental equipment for welding joints, the dissertation has presented three types of ultrasonic welding machines.

Vertical intermittent ultrasonic welding machine has a maximum welding power of 2 kW and oscillation frequency of 20 kHz; welding and holding time can be adjusted from 0.2 s to 4 s; the maximum welding pressure is 5 kg/cm2.

Continuous axial ultrasonic welding machine and radial ultrasonic welding machine have frequency and power of 20 kHz and 1 200 W respectively; the maximum value of the amplitude of mechanical vibrations on the surface of the ultrasonic horn is 60 μm; the roller speed is controlled and adjustable at 6m/min; The air pressure in the compressed air system to create welding pressure from the roller (anvil) to the welding horn can be up to 5 kg/cm^2.

The basis for the standard data processing method has also been presented in Chapter 3, including steps to conduct experimental planning, using the Taguchi method combined with the FCCCD method to evaluate the influence on each factor and obtain a quadratic regression equation; thereby, selecting a reasonable welding pattern and determining the domain of optimal process parameters for the ultrasonic welding process for nonwovens.

Finally, the supporting equipment for the process of determining the durability of the weld and the analysis on the microscopic image of the welding joints are also introduced by the dissertation such as: multi-function tensile test Instron - 3369, Scanning Electrical Microscope (FE - SEM) HITACHI S - 4800.

Chapter 4: Results and Discussion

Chapter 4 introduces the process of designing, simulation, manufacturing different types of ultrasonic systems for two welding processes: intermittent and continuous welding. Welding equipment has also been presented in detail from the principle to the actual fabricated model. In order to evaluate the breaking tensile strength of the weld seam, the measuring equipment sample, the factors that are the process parameters were also tested to evaluate the influence on the breaking tensile strength of the weld seam, to determine the number of tests. The iterative test is 7 experiments, selecting a regression model in the form of polynomial of order 2, using a combination of the Taguchi method and experimental planning of order 2, which is a response surfaces method in the form of FCCCD.

The results of the experiment to evaluate the factors that have the most influence on the breaking tensile strength of the weld seam are: welding time rate 45.31%, weld shape (sample 3) rate 30.03%, and welding pressure 24.66%.

The dissertation also finds the domain of optimal process parameters for each type of welding sample through regression equations and illustrative charts for the tensile strength levels of the weld. From there, it analyzes and evaluates the cases in the domain of process parameters to ensure that the tensile strength reaches the lowest given value of 200 N, 220 N and 240 N for welded samples.

In addition, to explain the formation and texture of ultrasonic welds on nonwovens, the dissertation has presented microscopic images of the welds taken from different angles.

With the selected welding parameters, the welding temperature has reached near the glass temperature area T_f in the region of the viscoelastic state of the PP material. Then the PP non-woven fabrics will bond well together.

Chapter 5: Conclusions and Future works

Chapter 5 presents the achieved objectives of the dissertation such as: studying the theoretical basis of ultrasonic welding process for thermoplastic materials; researching and manufacturing axial and radial ultrasonic welding horns with a frequency of 20 kHz; experimenting ultrasonic welding on non-woven fabrics; conducting a weld seam quality analysis with major sets of process parameters; optimizing major process parameters using the Taguchi method combined with the FCCCD method.

In addition, the conclusions of the dissertation were also presented, including:

Investigation of ultrasonic welding applications for thermoplastics, non-woven fabrics: thermoplastics PP has an amorphous structure, so ultrasonic welding is done easily. In addition, when the PP nonwoven fabric is ultrasonically welded at 20 kHz, the recommended vibration amplitude is 38 μm.

Research on the theoretical basis of ultrasonic welding, thermoplastic materials: for PP nonwoven fabric with quantitative of 70 GSM welded together at a frequency of 20 kHz, the oscillator amplitude increases the initial oscillation amplitude from 22 μm up 2 times. In addition, the ultrasonic welding horn also increases the vibration amplitude by 1.5 times. Therefore, the maximum amplitude of oscillation when welding is about 66 μm. To ensure the safety of the equipment, the actual welding oscillation amplitude is only about 70% of the maximum value.

Research, design and manufacturing of axial and radial ultrasonic welding horn: for the 7075-aluminum alloy axial wide plate and the frequency of 20 kHz, the working size of 260 mm x 15 mm will create irregularities uniform in amplitude. A finite element analysis using Abaqus software revealed a degree of amplitude unevenness across the entire working area of the horn. Changing the shape and size of the welding horn will overcome this limitation. For a 7075-aluminum alloy radial horn and a frequency of 20 kHz, amplitude unevenness occurs over the entire circumference. Changing the shape and size of the welding horn will create amplitude uniformity, which is verified by finite element modeling.

Experimental ultrasonic welding on non-woven fabric: PP nonwoven fabric with quantitative of 70 GSM is welded with 09 different weld shapes. Based on the highest strength, Model 3 and Model 4 welds are selected. Based on experimental results, welding time (1.2 s; 1.6 s; 2.0 s), welding pressure (2.5 kg/cm^2; 3.0 kg/cm^2; 3.5 kg/cm^2) were selected for the determination of the main welding parameters.

With the above welding technology parameters, the welding zone temperature has achieved near the glass temperature area T_f in the region of viscoelastic state of PP material. At that time, the non-woven fabrics will reach a viscoelastic state so that they can be dissolved together to create good bonds, meeting the requirements for durability as well as weld quality.

As a result of image analysis of the weld seam through scanning electron microscope, the main areas of the weld such as welding area, border area, background material area are clearly distinguished. The fabric fibers in the welding area are compressed, partially or completely melted, so they are deformed compared to the original shape. In the hem zone, the fibers are only deformed and less melted.

Optimization of the main process parameters using the Taguchi method combined with the FCCCD method to determine the appropriate breaking tensile strength as required: an experimental process is conducted to determine that the maximum breaking tensile strength of the ultrasonic welding of nonwovens reaches about 79 % of the tensile strength of the starting material. The degree of influence of process parameters on the tensile strength of ultrasonic welds: shape of the weld zone, welding time and welding pressure with different degrees of influence, in which the influence level of welding time t is 45.31%, weld shape is Sample 3 with the rate of 30.03% and welding pressure is 24.66%. Regression equation for the selected types of welding samples is obtained, thereby determining the process parameter areas suitable for the requirements of the weld strength. For sample 3, the highest breaking tensile strength was obtained at 253.73 N when t = 1.62 s and welding pressure p = 3.1 kg/cm^2.

For sample 4, the highest tensile strength was obtained at 224.67 N when t = 1.6 s and welding pressure p = 3.09 kg/cm^2. Carrying out a verification test with welding parameters: t = 1.6 s, p = 3.1 kg/cm^2, 2 types of welds (Sample 3 and Sample 4), we have the result of breaking tensile strength for Sample 3, with a deviation between the calculated results and the actual experimental results: 1.19%. Sample 4 has a deviation between calculated results and actual experimental results: 0.77%.

Publication

International scientific journal

1. Thanh Hai Nguyen, Quang Thanh Le, Huu Loc Nguyen, and Dang Khoa Truong (2021). Design of a radial ultrasonic horn for plastic welding using finite element analysis. *Japanese Journal of Applied Physics*, *60*(9), 096502. (SCIE - Q2, IF 1.480)

2. Thanh Hai Nguyen, Le Quang Thanh, Nguyen Huu Loc, Manh Ngo Huu, Anh Nguyen Van (2020). Effects of different roller profiles on the microstructure and peel strength of the ultrasonic welding joints of nonwoven fabrics. *Applied Sciences*, *10*(12), 4101. (SCIE - Q2, IF 2.679)

Domestic journal

1. Lê Quang Thành, Nguyễn Thanh Hải, Nguyễn Hữu Lộc (2020). Thiết kế máy hàn siêu âm quai khẩu trang y tế. *Tạp chí Cơ khí Việt Nam*, Số 3, Trang 101-103. ISSN 0866-7056.

2. Lê Quang Thành, Trương Đăng Khoa, Phạm Đức Lâm (2018). Thiết kế, chế tạo dây chuyền sản xuất túi vải không dệt sử dụng công nghệ hàn siêu âm. *Tạp chí Cơ khí Việt Nam*, Số 8, Trang 63-66. ISSN 0866-7056.

3. Nguyễn Thanh Hải, Lê Quang Thành, Trần Công Luật (2018). Thiết kế, chế tạo máy hàn nhựa nhiệt dẻo sử dụng dao động hàn siêu âm tần số 20kHz. *Tạp chí Cơ khí Việt Nam*, Số 1,2, Trang 99-102. ISSN 0866-7056.

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1. Thanh Hai Nguyen, Quang Thanh Le, Cong Luat Tran, Huu Loc Nguyen (2017, October). Investigation the amplitude uniformity on the surface of the wide - blade ultrasonic plastic welding horn. In *IOP Conference Series: Materials Science and Engineering* (Vol. 241, No. 1, p. 012023). IOP Publishing. (Scopus).

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2. Lê Quang Thành, Trần Công Luật, Nguyễn Hữu Lộc, Nguyễn Thanh Hải (2016). Nghiên cứu đặc tính hàn siêu âm trên bao bì nhựa, *Hội nghị Khoa học và Công nghệ toàn quốc về Cơ khí* - *Động lực 2016*, NXB Bách khoa Hà Nội, Trang 259-262, Hà Nội - Việt Nam.

3. Thanh Hai Nguyen, Quang Thanh Le, Phuong Minh Luu, Huu Loc Nguyen (2015). Manufacturing of Ultrasonic Horn for Bonding Non-Woven Materials. *National conference on machines and mechanisms 2015*, NXB Đại học Quốc gia Thành phố Hồ Chí Minh, Tp. Hồ Chí Minh - Việt Nam. ISBN 978-604-73-3158-7.

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