Development of a Device for Brazing Copper Pipes in HVAC Installations

*Sydney Olandria, John Vincent Cabesas, Dominic Geganto, Brent Kenneth Olivar, Gerald Osa, Angelo A. Acenas**

Department of Mechanical Engineering, Cebu Institute of Technology University, Cebu City, Philippines

*angeloacenas@gmail.com

ABSTRACT

The brazing process plays a crucial role in HVAC installations, particularly in joining copper pipes. However, current brazing methods are often unsafe, time-consuming, laborious, and prone to inconsistencies. Interviews with construction workers involved in the process have highlighted the hazards associated with brazing in construction areas where conventional groundworks lack suitable devices. To address these challenges, this study developed a new device specifically designed for brazing copper pipes in HVAC installations. During the design phase, simulation techniques were employed to carefully consider factors such as thermal stress, heat distribution, and deformations caused by applied heat. This approach ensured that the final design would optimize performance and minimize risks. Subsequently, an actual prototype of the device was developed and has demonstrated significant potential in improving soldering in terms of safety and efficiency. The effectiveness of the device was evaluated through comprehensive testing, revealing noteworthy enhancements in production and accuracy rates. To fully realize its potential, it is strongly recommended to provide operators with thorough safety training. Clear guidelines on handling and positioning the device and the MAPP gas should also be provided to ensure safe and proper usage.

Keywords: *Brazing, Soldering, Copper pipes, HVAC installation*

Introduction

The installation of heating, ventilation, and split-type air conditioning (HVAC) systems in residential, commercial, and industrial settings often requires the precise joining of copper pipes. These pipes serve as crucial conduits for refrigerant flow, ensuring efficient cooling and heating performance [1]. One common method for joining copper pipes in HVAC installation is brazing. Brazing involves applying heat and adding a filler metal to join two pieces of metal. The filler metal, which has a lower melting point than the metals being joined, is either pre-placed or fed into the joint as the parts are heated [2, 3].

However, current brazing techniques often result in braze joints that leak and require rework or, in some cases, scrapping of the entire component. The costs associated with poor internal braze quality can be significant, depending on the equipment size, number of joints requiring rework, labour costs, and component scrap costs [4]. Interviews with workers involved in the brazing process from an HVAC company have revealed that the existing practice is challenging and time-consuming, requiring skilled personnel and meticulous attention to detail. Inefficient soldering techniques have led to subpar connections, resulting in leaks, reduced system efficiency, and potential system failures. Additionally, the traditional or manual soldering method for preparing materials often leads to issues such as burning hazards. Hazards like burns, eye damage, electrical shock, cuts, and crushed toes and fingers are all potential risks associated with soldering copper pipes [5]. Improper handling of the welding torch, which is used to melt the welding rod and solder the connected copper pipes, can cause burns. Welding torches typically use oxygen and acetylene, producing flames with temperatures ranging from 2760 degrees Celsius to 3316 degrees Celsius [6].

Various inventions related to brazing can be found in patent databases, including a small-diameter pipe extrusion and soldering sealing device [7], an automatic solder spraying machine for pipe fitting [8], a welding device for air conditioner refrigeration copper pipes [9], a copper pipe joint with preset solder [10], and a welding apparatus for copper pipes [11]. However, these existing inventions suffer from two main drawbacks: a lack of portability and a complex design, making it difficult for unskilled workers to utilize the devices effectively.

To address these challenges, this research focuses on the development of a device for brazing copper pipes in HVAC installation. The primary goal is to overcome accidents and health hazards associated with the manual brazing process by providing a stable and secure platform for holding the copper pipes in precise positions. The development of this device involved careful consideration of factors such as tube alignment, heat distribution, soldering flux application, and joint quality control. The effective utilization of this device can help prevent injuries and enhance the overall working conditions for individuals in the industry. Moreover, this device has the potential to significantly improve both the operation time and accuracy of the brazing process, resulting in cost savings and increased productivity.

Methodology

The purpose of this study was to create a device that would enhance the brazing of copper pipes, thereby lowering or eliminating harmful working conditions and increasing efficiency. First, surveys that were given to employees of an HVAC installation firm, who acted as the target users, were used to gather qualitative data. These surveys seek to learn more about respondents' opinions and issues with the existing brazing procedure. The preferences of the intended users were then taken into consideration when the qualitative findings were examined to determine potential areas for process improvement. A conceptual design was then developed using the principles of machine design and heat transfer. The design was modelled in SolidWorks to acquire important insights into thermal stresses, heat distribution, and part deformation brought on by applied heat. After the simulation phase, the device was fabricated and put through a series of actual testing.

Design conceptualization

Since the goal is to address the issues faced by workers during HVAC installation, the results of the conducted survey, along with the insights gained from the value proposition canvas and cause-and-effect diagram, were used to develop the user preferences for product design. These preferences are presented in Table 1.

Table 1: User preferences for product design

Preferred Feature	Description
Ease of use	The device is user-friendly, especially for novice workers.
Labor reduction	The device simplifies and accelerates brazing work, requiring less manual labor.

Based on the table, two key themes emerged from the conducted survey: Ease of use and labor reduction. This indicates that workers prefer a device that is user-friendly, even for novice workers. Additionally, they desire a device that simplifies the brazing process, accelerates the work, and minimizes the need for manual labor.

Design and material selection

Using knowledge of machine design, the device was constructed as shown in Figure 1.

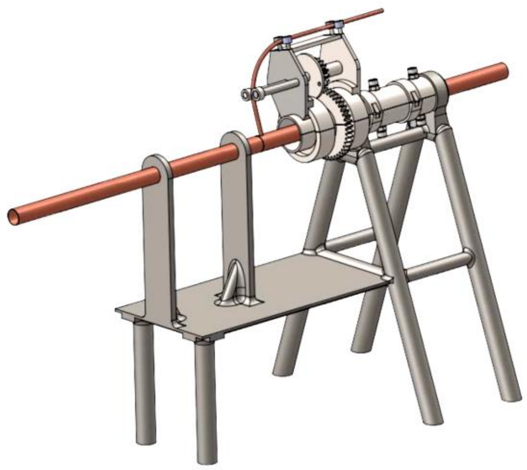

Figure 1: Ground assembly of the device

The selected materials for the device include alloy steel, engineering plastic, and aluminum alloy. Alloy steel is used for the body components such as gears, housing, shafts, and feeder. Engineering plastic is utilized for the soldering filler holder, while aluminum alloy is used for the clamps. The choice of these materials was based on their availability and suitability in terms of their physical and mechanical properties [12,13]. Alloy steel was chosen for its desirable density, hardness, toughness, thermal conductivity, and coefficient of thermal expansion. Similarly, aluminum alloy and engineering plastic were selected for their toughness, hardness, thermal conductivity, and corrosion resistance. The material selection is summarized in Table 2.

Table 2: Material selection

Parts	Material selected
Pinion, Ratchet, Gear, Feeder, Rotating housing, Ratchet pin plate, Ratchet pin, Pinion shaft, Gear tube housing	Alloy steel
Clamp	Stainless steel
Filler holder	Nylon 101

Analysis

Prior to fabrication, extensive calculations and simulations were conducted to ensure that the device meets the desired performance requirements [14,15]. The detailed results of these calculations and simulations are presented in the following sub-sections.

Design consideration

The following factors were considered during the design process and fabrication of the device:

a. The device must be capable of securely holding copper pipes of three different sizes: ½, ¼, and 3/8 inches in diameter.
b. The device must be able to handle the heat released by the MAPP gas.
c. The device must prioritize safety in both operation and maintenance.
d. The device should be cost-effective to manufacture and operate.
e. The device should be compact and user-friendly.
f. The device must facilitate a clean and precise soldering process.

Heat transfers

The heat generated by the copper tube will radiate and impact the adjacent components of the device, leading to an increase in temperature. To determine the final temperatures of the surrounding parts of the device, SolidWorks Flow Simulation was utilized. The results, depicted in Figure 2, provide insights into the temperature distribution.

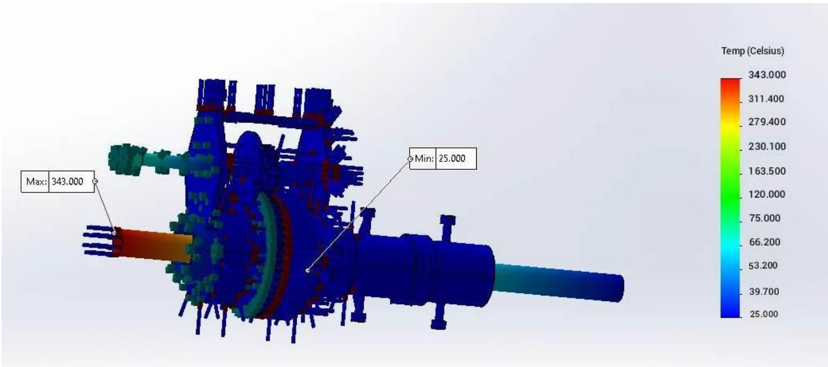

Figure 2: Temperature gradient across all parts of the device

Upon simulating the area affected by the heat radiated from the copper tube, it was observed that the feeders were impacted, as shown in Figure 3.

These results were further verified through manual calculations using Equation (1) which resulted in a temperature of 71 degrees Celsius for the feeders.

$$Q = \frac{A_1 \sigma (T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{r_1}{r_2} + \frac{1 - \varepsilon_2}{\varepsilon_2}} \quad (1)$$

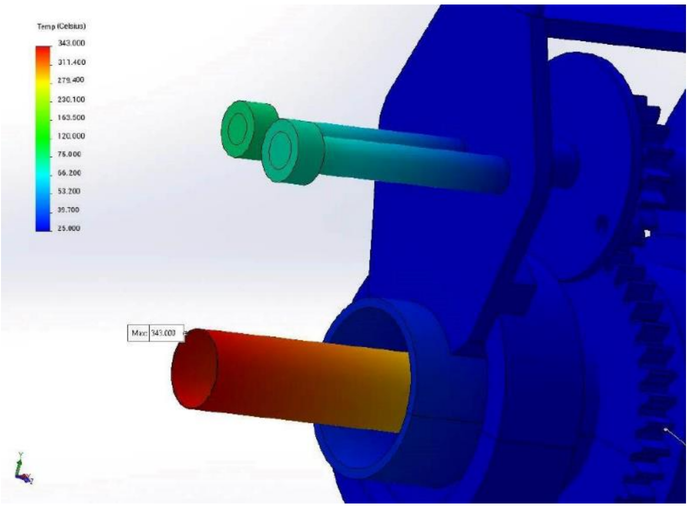

Figure 3: Temperature gradient for the feeder and shaft

Thermal stress

The heat radiation imposes stress on the device as the heated copper tube causes nearby parts to increase in temperature. Figure 2 illustrates the temperature gradient across all parts of the device, while Figure 3 specifically displays the temperature gradient for the feeder and shaft, ranging from 66.2°C to 75°C. To ensure safety, it is important to consider the maximum temperature. To calculate the thermal stress, Equation (2) was utilized which resulted in a calculated stress of 125 MPa which is less than the yield stress of 620 MPa. Therefore, the design is safe from thermal stress.

$$\sigma_T = E\alpha\Delta T \tag{2}$$

Deformation due to applied heat

Since the feeder and shaft are not constrained in a single direction, they are anticipated to expand in all directions. As a result, their deformation per unit length can be expressed using Equation (3). The expansion was calculated as 0.000468 per mm which is negligible.

$$\frac{\delta_T}{L} = \alpha\Delta T \tag{3}$$

Fabrication

The fabrication process of the device involves a series of steps which included the following steps:

a. Prepare the materials: The materials for the device consist of alloy steel plates for gears, housing, and stand, stainless steel for clamps, nylon 101 for the soldering filler holder, and bolts and nuts. These materials need to be cut and shaped to fit the device design.

b. Fabricate the gear housing and rotating housing: The gear housing, which serves as the main body of the device, holds all the parts except for the stand used in ground assembly. It is constructed from alloy steel pipes and plates. The fabrication process involves cutting and welding the pipes and plates to achieve the desired shape.

c. Fabricate gears, ratchets, shafts, pins, and ratchet plate: Gears can be fabricated using a gear hobbing machine or a CNC wire cut machine. Other components are fabricated through cutting, welding, and machine operations.

d. Assemble the parts in the rotating housing: This step involves assembling the pinion, shaft, ratchet, ratchet plate, and pin within the rotating housing. The shafts are connected to the pinion and/or ratchet using press fitting, while other connections are secured with screws. Some assemblies may require calibration to ensure proper functioning.

e. Assemble the gear to the gear housing: Prior to attaching the gear to the gear housing, both components are cut in half. The gear is then welded in place, and clamps are attached using set screws. Nuts are also welded onto the housing concentric to the existing holes.

f. Assemble the rotating housing to the gear housing: Since both the gear housing and the gear are cut in half, the rotating housing is slide-fitted into the channels allotted in the gear housing. It can also be secured in place with a set screw.

Performance evaluation

In line with the objectives of the study, the following parameters were used to evaluate the machine's performance:

a. Heat distribution and thermal stress
b. Production rate
c. Accuracy

Results and Discussion

Heat distribution and thermal stress

The heat distribution in both simulation and actual testing is presented in Table 3. The difference in the result can be attributed to several factors. One specific factor is the positioning of the MAPP gas. The direction in which the flame of the MAPP gas is pointing can cause temperature variations in different parts of the tool. The testing was conducted with the flame directed perpendicular to the copper tube, resulting in the heat being directed away from the tube. However, during actual heating, the flame covers half of the circumference of the copper tube facing the flame, causing the heat to disperse in the direction of the tool. On the other hand, in the simulation, the heat was only directed towards the end face of the copper tube and was confined to the end face cross-section, leading to an increase in temperature at the feeder.

Table 3: Actual and simulation results of heat distribution

Parts	Actual	Simulation
Feeder	75 °C	61 °C
Rotating housing	30 °C	39 °C
Gear tube housing	30 °C	35 °C

The thermal stress experienced by the device is within acceptable value (<620 MPa). On the other hand, the thermal expansion is negligible. The results are summarized in Table 4. Previous studies have also examined the importance of thermal stress and thermal expansion in the design of soldering or brazing operations [16, 17, 18]. These studies have shed light on the significance of these parameters in the overall design process.

Table 4: Actual and simulation results of thermal stress and expansion

Parameter	Actual	Simulation
Thermal stress	125 MPa	98 MPa
Thermal expansion	5.95E-4 mm/mm	4.68E-4 mm/mm

Production rate

The device's actual performance is tested by measuring the average production rate for three specified diameters of copper pipes: ½, ¼, and 3/8 inch. The production rate is calculated based on the number of workpieces completed per minute. Figure 4 depicts the comparison of the results with and without using the device. The results demonstrate a significant increase in the overall production rate due to the implementation of the device. This finding aligns with previous studies that have also highlighted the positive impact of technology adoption on improving productivity in the HVAC industry [19, 20].

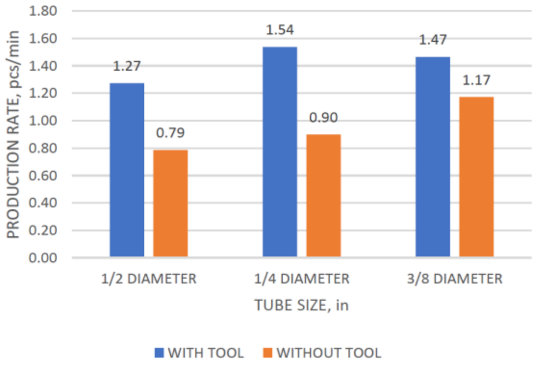

Figure 4: Average production rate with and without the device

Accuracy

Figure 5 depicts the actual performance results of the device, specifically focusing on accuracy, as tested with copper pipes of three specific diameters: ½, ¼, and 3/8 inch. Accuracy is determined by calculating the ratio of accurately produced workpieces to the total number of completed workpieces. There was an overall improvement in accuracy because of the intervention of the device. This result further reinforces the significance of accuracy in the brazing operation, building upon previous findings [21,22].

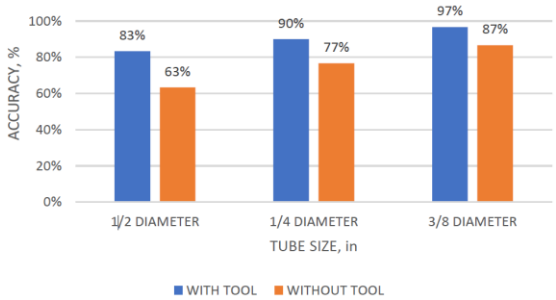

Figure 5: Average accuracy with and without the device

In lieu of the findings above, to effectively implement the designed and fabricated device for brazing copper pipes in construction sites, consideration should be given to the specified diameters and the tool's versatility for both overhead and ground operations. Proper training and instruction are crucial to maximize the tool's benefits and ensure safety. Continuous monitoring of the tool's performance, usability, and safety through user feedback and periodic assessments is recommended, allowing for necessary improvements. Future research should focus on investigating the device’s long-term durability, exploring its adaptability for other materials and joint configurations, and addressing ergonomic design considerations to enhance user comfort and reduce fatigue.

Conclusion

The study developed a device for brazing copper pipes in HVAC installation which has effectively addressed concerns regarding the work environment and workplace safety and the need for multiple personnel. The device demonstrates the potential to enhance the brazing process in terms of safety and efficiency. The simulation provided valuable insights into heat distribution, thermal stress, and thermal expansion encountered by the device. Actual testing demonstrated higher production rates and improved accuracy when using the device compared to the existing practice.

Contributions of Authors

The authors confirm the equal contribution in each part of this work. All authors reviewed and approved the final version of this work.

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Conflict of Interests

All authors declare that they have no conflicts of interest

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