Design of Frangible Composite Production Process and Plant Layout with Powder Metallurgy Method and Capacity of 50,000,000 Rounds/Year

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Abstract. Frangible composite material is one of the types of advanced material utilized by defense technology application which has been certified. In fact, this material is in development for mass production. In order to realize the mass production stage, it is necessary to have a comprehensive design on process production, specification, machine capacity and the blueprint of plant’s layout. Production process planning would be conducted by the target up to 50 million rounds per year. This process uses powder metallurgy method which consists of mixing, compaction, sintering, finishing, quality control, and packaging. This research would result various variable and constants in each processes, plant design, specification, and number of machines needed by using data from literature review and previous research. Then, the number of machines is going to be calculated in order to find the certain number of machines that are needed. The calculation implies the needed of production machines which are 1 unit of mixer, 3 units of automatic mechanical compaction machine, 1 unit of continuous sintering furnace, 1 unit of finishing machine, and 3 units of quality control machines. For the production process simulation, we use Tecnomatix Plant Simulation in order to simulate the processes to get the data. The simulation process would be started by inputting the total number of machines that are used by and the variables and constants in each process which had been determined before. By calibrating the running time for 365 days 3 hours 15 minutes, the result stated that the simulated production process produced the number of outputs of 50,037,120 rounds/year and 45,696 rounds per shift.

Keywords: Composite, Frangible, Powder Metallurgy, Production Process, Plant Layout

1. Introduction
One the main requirement of defense equipment is ammunition. Recently, ITS developed frangible composite based ammunition which is planned for mass production, but currently has no integrated production line. The production process of frangible composite uses powder metallurgy method due to the frangibility factor which is only obtained by this method. Generally, the stage of processes consists powder mixing, powder compaction, sintering, finishing, and quality control.

The powder mixing is conducted in order to get the powder mixture by a double cone mixer. Then, the next process is powder compaction process by using automated compaction machine. The
next step is sintering process which uses continuous sintering furnace. The last step is quality control process using conveyor scale and optical micrometer sensor. This research intends to determine the variables and constants of each processes and also to calculate the exact number of machine needed, all to achieve the goal of a 50 million rounds/year production capacity.

After determining the variables, constants, and number of machine needed for each processes, the plant layout design is conducted using CORELAP algorithm to reduce the material handling cost [1]. First, the production department layout is determined according to the process flowchart and it will be fixated because the flow of process cannot be rerolled. Then, CORELAP algorithm is conducted using supporting department and the fixated production department. Total Closeness Rating (TCR), which determines the degree of closeness for each department with each other, is determined and calculated. The departments are then ordered based on their TCR descending. Then, the departments are placed in the plant layout according to the order. This will result in an Area Allocation Diagram (AAD) which serves as a base for designing the final layout. The AAD is then given allowance for material handling in each processing department, which will improve production output, reduce bottleneck and delay, and reduce material handling cost [2].

For the final part, the production process is then simulated using Tecnomatix Plant Simulation, with the inputs are running time, number of machines, type of processes (batch or continuous), and processing capacity. The simulation process will give the designed production process its production capacity for its given running time, which is a year full of production. The result is then analyzed, whether it reached the production target of 50.000.000 rounds/year or not. If the result did not meet the expected target, a new design is iterated by recalculating number of machines and determining the variables and constants for each processes.

2. Experimental method

2.1. Research Location
The plant of frangible composite would be established within the building of 12 meters x 12 meters and the area of 144 m². This mini plant has 3 main sections of manufacturing which are production line of frangible composite material, production line of atomization to yield the powder that would be used for frangible composite, and the office section for administration and non-technical activity.

2.2. Determination of Stages within Production Process
The production process uses powder metallurgy method, which is mixing, powder compaction process, sintering, finishing, quality control and the last one, packaging [3]. This research would be carried out of fixation upon the variable and constant in each process that the production process of frangible projectile can work properly and obtain the product who met the specifications. These stages consist of but not limited to: 1. Mixing, 2. Powder compaction, 3. Sintering, 4. Finishing, 5. Quality Control, 6. Packaging.

2.3 Processing Time
In this stage, the timing process would be determined for each process to decide the specification and the total number of machines working for, in order to achieve production target. Assuming the failure rate is about 10% on compaction process, sintering and quality control, the production target in each process could be determined by:

\[
\text{Initial production target} = \frac{\text{Final production target}}{\left(1 - \text{failure rate}\right)}
\]

2.4 Specification and Quantity of Machine
The total number of machines from machine’s specification and production target can be determined by:
Generally, there are six sections of facility and production service within the company which are Production department, Warehouse, Meeting room, Office, Prayer room, Toilet, and Parking lane.

### 2.5 Activity Relationship Chart (ARC)

Activity Relationship Chart (ARC) is a diagram used for obtaining relationship from specific activities in order to determine where the activity which has to be adjacent or otherwise within the layout design of a facility. ARC consists of production activity and service activity.

In explaining the adjacency relation among departments, we use Activity Relationship Chart by inserting several symbols as follows on Table 1:

| Degree of Closeness | Description                  |
|---------------------|------------------------------|
| A                   | Absolutely Necessary         |
| E                   | Especially important         |
| I                   | Important                    |
| O                   | Ordinary                     |
| U                   | Unimportant                  |
| X                   | Undesirable                  |

### 2.6 Total Closeness Rating (TCR)

In this step, the calculation process of TCR value would be conducted. The assessment is conducted by adding the total closeness rating of an activity or department based on criterion within Table 2 and ARC diagram that has been created [3].

| Degree of Closeness | Description                  | Color Code | Weight | Closeness Rating |
|---------------------|------------------------------|------------|--------|------------------|
| A                   | Absolutely necessary to be adjacent | Red        | 243    | 6                |
| E                   | Very important to be adjacent | Orange     | 81     | 5                |
| I                   | Important to be adjacent     | Green      | 27     | 4                |
| O                   | Ordinary adjacent            | Blue       | 9      | 3                |
| U                   | Unnecessary to be adjacent   | White      | 1      | 2                |
| X                   | Unexpected to be adjacent    | Brown      | 0      | 1                |

### 2.7 CORELAP Analysis

After the value of TCR is obtained, each production or facility section have to be conducted CORELAP algorithm calculation. The step of CORELAP algorithm can be started by the calculation of Total Closeness Rating (TCR) for each departments. The first step is to choose the department with the highest value of TCR and putting it in the center of layout. Then, if there are equal value, we take the department with the largest area. We place the departments correlating with A and already selected, then the correlation of E, I, O, U and X. If there are same criteria, we use the department with the largest area. If the department has been chosen, the placement is decided based on Placing Rating which is the sum of
weight closeness rating among departments that has been inserted and that will be inserted. If the placing rating is equal, then the border length or total units per square that are side by side will be compared.

2.8 Area Allocation Diagram

After we get the layout with the most optimum layout score, we can proceed to the Area Allocation Diagram (AAD) scheming stage. AAD is a description of layout in a global scope representing closeness relationship among sections and the area scale of exact floor.

The AAD process will be conducted twice and separately between production section and production facility. The production section will be organized first. Then. It is combined by production facility yielding the layout of a whole mini plant that want to be constructed [3].

2.9 Production Line Simulation

Production line simulation is conducted by using software Tecnomatix Plant Simulation. In simulation method, we can assume that the machine is operating, corresponding with the type of process whether it is batch or continuous. The Variable that will be inputted are type of process, production capacity in a cycle, processing time, and total of machines.

3. Results and Discussion

3.1 Production Process

The method used for producing frangible composite material is powder metallurgy method. The parameter determination in each process in this method is organized by considering previous research and related literature.

The powder mixing is conducted by fixation process upon various variable to be used as a constant within production process design of frangible composite material Cu-10% Sn. We used wet mixing process with mixing media of ethanol, due to its low boiling point temperature (78.37°C) [4]. That variable produced frangible composite material with the best result therefore it is used as a constant in powder mixing process.

The type of compaction process that is used is single action because of its ability to give high strength and high density to the part which is directly contacting with moving punch [5]. The temperature while compaction processing is cold compaction, without heating process. The reason that we used cold compaction method is because tin, as the matrix of the composite, has low melting point which is 232°C. Accordingly, it does not need to combine sintering process with high pressure. The utilization of cold compaction is to reduce the working time because there is no heating and cooling process and to reduce the cost of die because hot compaction needs a die with resistance of high temperature [4]. The variable constant of compaction pressure for production can be obtained from previous research where the mechanic test implied that the best result was resulted by compaction pressure of 700 psi.

Liquid sintering process is able to create intermetallic compounds, Cu₃Sn and Cu₆Sn₅ which increase the mechanical properties of Cu-Sn [6]. Sintering process within industry, is carried out on liquid state because the solubility of solid within liquid can be filled in the porosity, so it can improve the mechanical properties [7]. Pre-sintering temperature that is used is about 100°C in 3-5 minutes [8]. Sintering temperature used is 260°C with 30 minutes of working process [9].

One of the types of finishing process which are compatible to be used for this frangible composite is vibro-abrasive. It is also known as rumbling or tumbling because it is able to process many objects instantly [10]. The finishing media used is porcelain VZ EB 0610 weighting 25 kilograms and liquid booster FEL120-B32 weighting about 50 grams [10]. The duration of the process is 180 minutes [10].

Previous research [9] stated that the mass of composite is 5.23 grams with tolerance ± 0.1 grams and the diameter is 9.02 mm with the tolerance ± 0.02 mm. Meanwhile, the simulation result shows that the optimum length of composite material is 16.0 mm with a tolerance of ± 0.8 mm.
Based on benchmarking result in various manufacturing company, shows that the aspect that is controlled by QC is weight and dimension because both of them affect the mechanical properties. In previous research also showed that the optimum frangibility factor of the frangible composite can be obtained on composite mass which are 5.23 grams with the tolerance ± 0.1 grams and diameter of 9.02 mm with the tolerance ± 0.02 grams. Meanwhile, the simulation result shows that the optimum length of composite is about 16.0 mm with the tolerance ± 0.8 mm.

The frangible composite material which do not meet specification will be rejected while QC process. Then, the rejected material will be collected for recycling. This will improve the salvage value from rejected material so it can be more efficient for production cost.

In packaging process, 100 (one hundred) composites are packaged into one box. Then, a silica gel is inserted and a plastic case is tightly wrapped to the package.

3.2 Production Target in Each Processes

Assuming the failure rate is about 10% in compaction process, sintering, and QC, initial production target can be calculated as follows in the Table 3.

| Processes    | Initial Production Target (rounds/shift) |
|--------------|----------------------------------------|
| Quality control | 50778                                  |
| Sintering     | 56420                                  |
| Compaction    | 62688                                  |

3.3 Specification and Quantity of Machines

For the next step to establish a production line is by deciding the number of machines which are needed and use the number of production target, production capacity, and processing time. To determine the number of machines which are needed use the control variable that consist of production target/shift (8 hours), working time, and plant rate. The calculation of the production target/shift (8 hours) determined by:

\[
Production\ target\ (\text{rounds/shift}) = \frac{Production\ target\ (\text{rounds/year})}{(\text{total\ days/year}) \left(\frac{\text{number\ of\ shift/day}}{}\right)}
\]

The results of the calculation of production target (rounds/shift) is 45700 grain/shift. The calculation is conducted in order to find the effective working time in 1 shift. Expected performance can be assumed 100%. The effective working time can be calculated as follows:

\[
Work\ time = 1\ shift\ (mins) \times Exp.\ Performance\ %
\]

The results of the calculation of work time are 28.800 seconds.

Plant rate is the target of production capacity that has to be achieved by machine. The value can be calculated as follows:

\[
Plant\ rate\ (\text{second/pcs}) = \frac{working\ time\ (\text{second})}{Production\ target\ per\ shift\ (\text{pcs})}
\]

The results of the calculation of plant rate (second/pcs) is (28800 seconds)/(45700 pcs). The specification and quantity of machines which needed in this line production as shown in Table 4.
Table 4. Specification and quantity of machines.

| Processes                        | Machine Capacity (seconds/rounds) | Total of Machines (units) |
|----------------------------------|----------------------------------|--------------------------|
| Continous sintering furnace      | 0.466                            | 1                        |
| Compaction                       | 1.333                            | 3                        |
| Mixer                            | 48.000                           | 1                        |
| Finishing                        | 0.276                            | 1                        |
| Quality control                  | 1.7                              | 3                        |

3.4 Departments of the Plant

Deriving from the number of machine needed, we can calculate the needed area of each department. Therefore, we can calculate the production section area and supporting production area. The data has been attached as shown in Table 5 for Production Section and Table 6 for Supporting Section.

Table 5. Production Section Data.

| No. | Section                        | Dimension (meter) | Area |
|-----|--------------------------------|-------------------|------|
|     |                                | Length | Width |      |
| 1.  | Loading Scrub Atomization       | 1.5    | 1.5   | 2.25 |
| 2.  | Scrub Preparation Atomization   | 1.5    | 3     | 4.5  |
| 3.  | Scrub Feeding Atomization       | 3      | 3     | 9    |
| 4.  | Atomization                     | 3      | 3     | 9    |
| 5.  | Mixing                          | 2      | 5     | 10   |
| 6.  | Compaction                      | 5      | 3     | 15   |
| 7.  | Sintering                       | 5      | 3     | 15   |
| 8.  | Finishing                       | 2      | 3     | 6    |
| 9.  | QC                              | 3      | 3     | 9    |
| 11. | Packaging                       | 2      | 3     | 6    |
|     | Total Area                      |        |       | 61   |

Table 6. Supporting Production Section Data.

| No. | Section  | Dimension (meter) | Area |
|-----|----------|-------------------|------|
|     |          | Length | Width |      |
| 1.  | Office   | 6      | 3     | 18   |
| 2.  | Manager Room | 3 | 3 | 9 |
| 3.  | Warehouse | 1     | 3     | 3    |
| 4.  | Toilet   | 3      | 3     | 9    |
|     | Total Area |       |       | 39   |

3.5 ARC Diagram of the Plant

Each sections of production is combined into one production section because the placement is based on the sequence of process. Then, the ARC diagram is made based on all supporting department and the production department, as shown in Figure 1.
Then, we can calculate TCR value in each section. Therefore, we get the sequence of placements which is shown in Table 7.

| No  | Section Name     | Total TCR | Area Section (m²) |
|-----|------------------|-----------|-------------------|
| 1   | Warehouse        | 76        | 3                 |
| 2   | Parking Area     | 58        | 24                |
| 3   | Toilet           | 18        | 9                 |
| 4   | Production Dept. | -12       | 61                |
| 5   | Office           | -12       | 18                |
| 6   | Manager Room     | -12       | 9                 |

3.6 Layout Design of Plant
Based on the sequence of placement in Table 5, the departments can then be placed according to the CORELAP algorithm rules. The results are as shown in Figure 2 and Figure 3 below.

3.7 Line Production Simulation
To simulate the production line, the variable and constant of each processes and total machines is inputted into the software Tecnomatix Plant Simulation 14. By this method, every machines can operate either continuously or batchly. The constant inputted is machine production process (continuous or batch), production capacity (pcs/cycle) and process time. Then, the model is simulated for 1 year 3 hours 15 minutes (365 days 3 hours 15 minutes). The Production output in 1 year is 50,037,120 rounds and production output in 1 hour is 5712 rounds.
Figure 2. Sequence of department placing by CORELAP Algorithm.

Figure 3. Final layout design.
Figure 4. Frangible composite production scheme as simulated in Tecnomatix Plant Simulation.
4. Conclusion
The result of this research implied that the plant layout design of frangible composite plant has been arranged and proven to produce 50 million rounds/year with powder metallurgy method. The total machine that are needed for this mini plant is as follows, 1 unit of mixer, 3 units of compaction machine, 1 unit of sintering furnace, 1 unit of finishing machine, and 3 units of QC conveyor. From the simulation of production line using Tecnomatix Plant Simulation, we get that the production output of the designed plant layout is 50,037,120 rounds per year with a running time of 365 days 3 hours 15 minutes.

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