This study is an experimental research to analyze the characteristics and mechanical properties of the casting process of recycled brass alloy, which will be used as a material for gears. Currently, the remaining production and waste from brass alloys continue to increase. Another thing is the increase in the need for brass gears, so environmentally friendly material engineering is needed to provide good quality and efficient energy use, especially during the casting process. The casting process uses an electric furnace that melts brass alloys at 526 up to 900 °C within 1 hour and molds to make test specimens. The results of microstructural testing for grain size in recycled brass alloys range from 74.63 μm to 84.57 μm. The maximum tensile strength produced is up to 225.2 MPa, the maximum yield strength is up to 179.8 MPa, and the maximum elongation is up to 7.3 %. The roughness of recycled brass alloys has a maximum Ra value (average roughness) of up to 0.836 μm. Validation was carried out by comparing the mechanical properties of CAC 302 brass products and the study results. The data shows that recycled brass's maximum yield strength value is 179.8 MPa and CAC 302 brass material is 175 MPa, but for the ultimate tensile strength value, the value of recycled brass is far below CAC 302 products. These results can be a consideration for the industry to be able to use recycled brass alloys for gear products because the yield strength value is not far from CAC 302 brass products. The impact result of this study produces recycled brass alloys that are environmentally friendly, efficient in smelting energy consumption, and have good yield strength. The results of this research can benefit the manufacture of gear components made of brass alloys

Keywords: environmentally friendly, gear manufacture, investment casting, mechanical properties, brass recycling

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EFFECT OF THE BRASS WASTE RECYCLING PROCESS ON MECHANICAL PROPERTIES WITH INVESTMENT CASTING FOR GEAR MATERIALS

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1. Introduction

The industry's need for brass materials will continue to increase in the next decade. Some brass materials are used in the automotive, renewable energy, medical, and aerospace industries. The significant growth in the use of brass must be balanced with the development of technology for brass recycling that maintains the quality of materials and is supported by energy savings from the material manufacturing process. Manufacturing process engineering by utilizing material recycling can provide benefits for economic growth. Brass material has advantages because it possesses good mechanical properties, so it has good potential to be developed to meet industrial needs.

One of the products of brass alloy that is in high demand is gear, so good product quality is needed, such as the mechanical properties of the alloy, if the recycled brass alloy is used. An in-depth analysis of the manufacturing process through investment casting is the proper process to obtain products that are not limited to dimensional size by paying attention to process time and temperature. Thermal control and process time affect energy efficiency during the manufacturing process.

Therefore, studies devoted to analyzing the impact of the application of recycled brass alloys processed by manufacturers through investment casting on the mechanical properties of gear products are of scientific relevance. So, the development of recycled brass alloys can provide a level of energy efficiency and maintain the quality of the final product.

2. Literature review and problem statement

Recycling brass products requires little energy, so it can impact an environmentally friendly process. The high volume of copper scrap sales globally, which has reached 6 million tons annually in the last two decades, has made the copper industry worldwide make efforts to regenerate copper scrap [1]. Therefore, a proper manufacturing process mechanism is needed to process copper scrap. Researchers are working to continue to develop recycled material engineering. This is due to the significant use of natural resources and energy in metal processing. A significant amount of brass scrap increases yearly, so an efficient material manufacturing technology is needed [2] to develop engineering technology through the brass recycling process for sustainability and to increase the availability of natural resources. One source of air pollution comes from the processing of copper scrap and other elements, so problems will arise from the recycling process of copper scrap [3]. Recycling brass scrap can potentially protect the environment by reducing the exploitation of natural resources. By recycling scrap metal, the impact on environmental pollution can be reduced, due to decreased energy use and saving limited natural resources [4]. Priorities for energy conservation need to be developed by reducing the refining process from natural resources. Environmental pollution and waste of natural resources can occur due to the direct disposal of slag from the smelting process, so effective material processing technology can impact economic aspects and hazardous waste disposal [5]. Control over the handling of hazardous waste from the manufacturing process is carried out to ensure that the output of the smelting process can be effectual and does not produce excessive emissions and slag. Environmentally friendly brass alloys are an essential issue that researchers will develop in the future to recover the impact of pollution from industrial activities [6]. The increased amount of scrap and waste from brass alloys harms environmental management. Engineering is needed to manufacture recycled brass alloy materials that are environmentally friendly. Environmentally friendly brass material engineering is necessary, especially for the energy efficiency of the manufacturing process. Through engineering, brass alloy scrap can reduce environmental pollution and improve the industrial economy.

The industry uses gears of many brass alloys. In power transmission, gear drive is integral to industrial design elements. In the future, the market for gears, drives, and transmission systems will continue to proliferate. Applications of gears for medium and low power are widely used in the automotive industry, automation, and medical technology [7]. The potential use of brass gears will continue to grow, especially in the electronics, oil, and gas industries. Gears are one of the machine elements widely used in industry, especially those made of lightweight materials such as brass, aluminum, bronze, copper, and polymers. The unique properties required of the gear are that it is compact, lightweight, has excellent performance, and meets the minimum possible operability [6]. Good performance is required from gear products to maintain the material's quality and in the application during the process. The gears that meet each other will rotate together to transfer the torque force. Changes in force on the torque, speed, and direction of the energy source are part of the work of a gear. In parts that do not rotate, it has a less good impact than the movement of other gears [8]. Good mechanical properties of brass alloy materials are necessary to anticipate the forces that occur during the application of the gear product. Light and non-ferrous metals have varying strengths, different levels of surface roughness, and undetectable wear rates [7]. The strength, hardness, and wear of brass alloy materials are essential to providing superior product quality. The loading and loading rates in gears are tested through tensile testing, and the impact of friction and mechanical performance in terms of energy consumption also needs to be examined [9]. Friction will often occur in gear products, so a good hardness level of brass alloy material is required. The failure of excessive friction on the gear's wing surface is due to the gear's unfit surface [10]. The level of roughness and surface clearance is essential in gear products. Precise products such as gears require low or smooth surface roughness [11]. The gear material's characteristics that affect the gear's operational movement include the strength and roughness of the surface of the gear material. Industrial needs are increasing in terms of using brass alloys in equipment and machinery, one of which is its components as gears. This is also in line with the growth of brass alloy scrap, which continues to increase. Therefore, it is necessary to engineer brass alloy scrap materials.

Recycling brass by casting can affect the elemental composition of alloys and microstructures and the quality of the casting results. Casting brass residue with heat treatment at a temperature of 350 °C can increase the hardness and strength of brass alloys [12]. The melting process of brass alloys can be carried out under melting temperatures and can potentially increase the strength and hardness of the alloy. The great benefit of the product fabrication process through casting several alloys of elements from solid to liquid is the best method today [13]. Investment casting is the proper process to produce alloy metals without being limited by dimensions. The microstructure of brass alloys consists of α and β phases, where the α phase is a soft phase with ductility or plastic deformation and high strength. This phase is not suitable for machining processes. Medium phase β has good hardness and resistance but less ductility [14]. In phase α, the alloy has high strength, and the β phase has poor ductility. This can be a consideration when carrying out the brass alloy fabrication process. In CuZn42 alloys, the average grain size in phases α and β is 25 μm [15]. Increasing the melting temperature of brass and reducing the casting speed can inhibit composite surface defects. Reducing the casting speed and increasing the melting temperature of brass alloys can reduce the potential for casting surface defects [13]. Regulating the temperature and casting time can potentially improve the surface quality of gear products. Efforts to improve the quality of brass alloy recycling casting with temperature settings that exceed heat treatment and time that is not too fast are needed. The impact of the recycling process of brass alloys with casting needs to be studied more deeply so that the quality of recycled brass products is close to that of brass products.

Recycling brass by casting can affect the alloy's tensile and yield strength. The element lead affects the strength and strain of brass alloys, but this element harms health and the environment, so the industry began to reduce the use of lead in brass alloys [16]. Lead elements in brass alloys should be considered to be replaced with other materials, such as nickel, manganese, and others. The brass alloy with 37 % elemental zinc has a homogeneous crystal structure, single phase, and cubic face center. Brass alloys have relatively medium strength; with heat treatment, the strength will increase in brass alloys [7]. The composition of brass elements will affect the mechanical properties of brass alloys. Tensile and yield strength and hardening rate will increase when the temperature drops. Plastic deformation mechanisms and slip dislocations occur in copper alloys [17]. The final tensile strength and machinability are influenced by the alloy's microstructure, phase distribution, morphology, and intermetallic compounds [18]. The microstructure of recycled brass alloys must be analyzed to determine their strength after fabrication. The average final tensile strength in brass alloys is 373 MPa, yield strength is 190 MPa, and elongation is 5 % [19]. The mechanical properties of brass alloys are influenced by elemental composition, crystal structure, heat treatment, and temperature during the casting process. The composition of recycled brass alloys can affect the material's mechanical properties. Therefore, an in-depth analysis is needed to confirm this.

The brass recycling casting process affects the surface roughness of recycled brass alloys. Accurate surface roughness values can affect the function of products with a strict precision level [11]. The surface roughness of the gear product can affect the gear's performance at the time of application. In order to obtain a good surface finish, it is necessary to minimize the level of hardness on the surface [8]. Gear products require a good level of hardness. The lowest average value of surface roughness of brass alloys is 0.63 μm, and the highest value of average surface roughness is 2.25 μm [18]. Crack conditions are caused by a void on the surface of brass alloys [20]. The casting process will affect the density, roughness, final tensile strength, yield strength, and wear resistance in the final product [20], so the dominant factor affecting the mechanical properties of the material and surface roughness is the recycling sorting process of brass alloys. Attention to the roughness of recycled brass alloys needs to be increased as it impacts the quality of the final product.

The amount of brass scrap continues to increase, and there is a need to use gears made of brass that are environmentally friendly and have good mechanical properties, so manufacturing material engineering is needed for the fabrication of the gear material. The details are as follows: The impact of brass recycling casting on the quality of the casting alloy and the impact of impurities and elemental composition of recycled brass alloys that affect the mechanical properties of gear materials are not yet known. The effect of the surface quality of brass recycling on gear materials and the influence of microstructures of recycled casting brass alloys on the strength of gear materials, as well as the influence of surface roughness of cutting tools from recycled casting brass alloys on the strength of gear materials are not yet explicitly known.

Relevant research is needed to overcome some of the aforementioned problems through an experimental research approach. From some of the above, it is recommended that a study be conducted on the impact analysis of the brass pad recycling process on mechanical properties through the investment casting method on gear materials. This research is essential because efforts continue to be made to engineer the recycling of brass alloys as high-quality, efficient, and environmentally friendly products. Recycled brass alloys fabricated through the casting process can potentially affect the characteristics and mechanical properties of the gear material. The problem today is that the source of scrap brass comes with different variations in composition, so it is necessary to test the composition and mechanical properties after the smelting process so that the quality of the material fabricated by the investment casting method meets the needs of the industry.

3. The aim and objectives of the study

The aim of this study is to identify the feasibility of using a brass waste recycling process with investment casting for gear materials.

To achieve this aim, the following objectives are accomplished:

– to conduct experiments with the investment casting method in the brass alloy recycling process;

– to conduct tensile tests to analyze the ultimate tensile strength, yield tensile strength and elongation values, and validate with CAC 302 brass products.

4. Materials and methods

The object of this research is the characteristics of the process and results of brass recycling casting.

This research is an experiment conducted in a metal casting and testing laboratory. This study hypothesizes that the gear material from recycled brass has the same mechanical properties and roughness level according to the needs of the industry. Assuming the gear material produced from this study has strength and is environmentally friendly. The application adopted from this study to obtain results that can meet the needs of the industry is to compare the material strength of existing products on the market with the results of recycled brass products. The independent variable is brass waste, and the dependent variable is the characteristics of the process and results of waste recycling casting consisting of slag, the composition of Cu and Zn elements, and the mechanical properties of the recycled brass alloy. The samples used in this study are leftovers from brass alloy production. The remaining brass alloy material is prepared to proceed to the casting process stage for specimen manufacturing, as shown in Fig. 1. The casting process of recycled brass alloys and the preparation process of specimen molding.

a *b*

Fig. 1. The casting process of recycled brass alloys and the preparation process of specimen molding: *a* – casting process; *b* – molding preparation process

The rest of the brass material is prepared in an electric furnace with a power of ±4.5 kVA and max temperature control. 1,000 °C is used to melt the remaining brass alloy. The brass melts at 526 °C up to 900 °C for 60 minutes. The melting process is carried out below the melting point of the brass alloy at 1,090 °C. The slag appears during the smelting process and is taken using a spoon from an electric furnace; then, the slag is weighed. Then, the pouring process is carried out into the specimen mold. Pouring is carried out by gravitational force, and the cooling process is carried out with the surrounding environment's air and finishing. Testing of the chemical composition, microstructure and content is carried out using Scanning Electron Microscopy – Energy Dispersive X-Ray Spectroscopy (SEM-EDX), tensile testing is performed to analyze tensile strength, yield strength, and strain, as well as surface roughness testing of recycled brass alloy materials. Fig. 2 shows the drawing of the tensile test results of specimens from the recycled brass alloy.

Linear regression numerical methods are used to verify the effect of brass alloy recycling on alloy recycling test results for gear materials. Developing experimental data and processing it using statistical tools and regression analysis techniques provided good results [21], so the linear regression numerical method is used to analyze the relationship between elemental composition and roughness. The scope of this study's results includes the casting process of recycled brass alloys that produce some slag characteristics and mechanical properties of recycled brass alloys, including Cu and Zn element composition, grain size, strength, and roughness.

Fig. 2. Tensile test results of specimens

5. Results of the experiment with the brass alloy recycling casting process and mechanical properties of materials

5. 1. Results of the brass recycling casting process

The initial weight of the recycled brass alloy is 2,492 g before the casting process is carried out using an electric melting furnace. During the smelting process, slag is produced by 144 g so that the final weight of the recycled brass alloy is 2,348 g. Details of the initial, slag and final weight of recycled brass alloys can be seen in Table 1.

Table 1

Initial, slag and final weight of the recycled brass alloy

Recycled brass alloys	Initial weight of CuZn recycled alloys (g) (*a*)	Slag weight during CuZn process (g) (*b*)	CuZn alloy final weight–slag (g) (*a*)–(*b*)
CuZn	2,492	144	2,348

From the data above, it can be seen that the initial weight of the recycled brass waste of 2,494 grams decreased by 5.77 % after the casting process, so the final weight was reduced.

5. 2. Characteristics and mechanical properties of recycled brass alloys

Elemental composition testing of copper (Cu) and zinc (Zn) was carried out at three surface points of the test sample, namely Area 1, Area 2, and Area 3. Data on each element's weight and atomic percentage can be seen in Table 2. Test results of recycled brass alloy composition with EDX.

Table 2

Test results of recycled brass alloy composition with EDX

Sample		Area 1	Area 2	Area 3
Copper (Cu)	Weight (%)	69.03	68.27	68.05
	Atomic (%)	69.63	68.89	68.66
Zinc (Zn)	Weight (%)	30.97	31.73	31.95
	Atomic (%)	30.07	31.11	31.34

From the composition test results, the weight percentage of copper (Cu) is between 68.05 % and 69.03 %, while the atomic percentage is from 68.66 % to 69.63 %. The weight percentage of the element zinc is between 30.97 % and 31.95 %, and the atomic percentage from 30.07 % to 31.34 %. The result of linear regression analysis for the relationship is 0.9081. Details can be seen in Fig. 3 below.

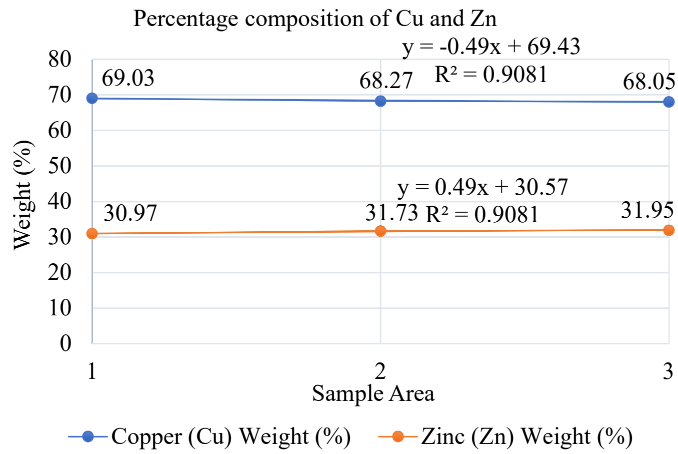


Fig. 3. Effect of Cu element composition on Zn

From Fig. 3, it can be seen that there is a strong influence on the increase and decrease of Cu and Zn elements. When the element Cu increases, the element Zn decreases, and instead.

Fig. 4, *a*–*c* shows graphs and areas of composition and microstructure testing points with 50x magnification. Fig. 4, *a* depicts the SEM-EDX test results in area 1, with the test focus on the specimen on the upper left side.

The test results of area 1 are described in Fig. 4, *a*, showing that the composition of Cu weight content has the highest value compared to areas 2 and 3. Meanwhile, the Zn weight content has the lowest value compared to areas 2 and 3. In area 2, depicted in Fig. 4, *b*, the test position on the specimen is carried out on the upper right side.

Fig. 4, *b* explained that area 2 has a weight composition of Cu of 68.27 %, between areas 1 and 2. Meanwhile, the composition of the element Zn is 31.73 %, with the same position between areas 1 and 2. Fig. 4, *c* shows the results of testing in the 3rd area with the position in the middle of the bottom.

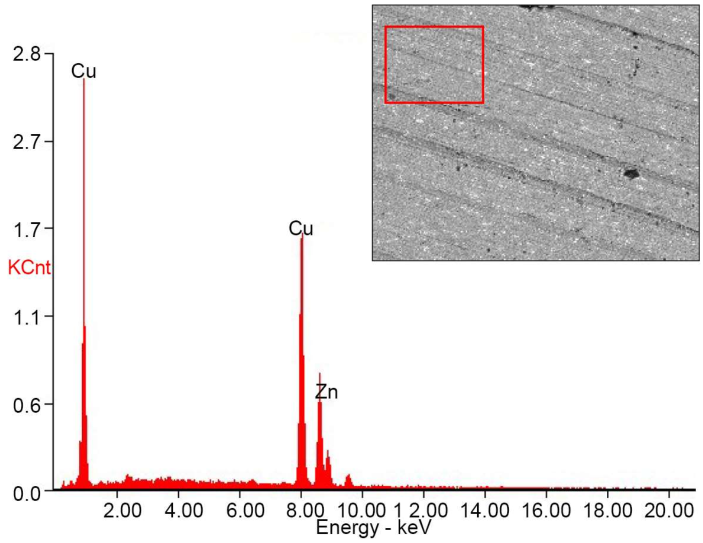
From the data of the composition test results in Fig. 4, *c* for area 4, it was found that the elemental composition of Cu had the lowest value compared to the test results of areas 1 and 2. However, the composition of the element Zn has the highest value compared to areas 1 and 2.

Specimens prepared for SEM testing are returned with 50x and 100x magnification, and grain size measurements are carried out using the Image J application. Fig. 5, *a* shows the microstructure results of the recycled brass alloy with 100x magnification.

From the microstructure image in Fig. 5, *a*, it can be seen that the grain size on recycled brass alloys looks varied, but some have more or less the same size. Fig. 5, *b* depicts the position of the grain size measurement point area of the recycled brass alloy. Five areas of the item will be measured through the Image J application. Therefore, areas of various sizes are set. From Fig. 5, *c*, it can be seen that there are holes and cracks on the surface. Cracks and holes can potentially occur in recycled brass alloy castings.

The results of the grain size measurements can be seen in Table 3 below. The lowest grain size was 21.85 μm, and the highest was 30.13 μm.

The average grain size of the recycled brass alloy is 26.06 μm. This size is about 1 μm larger than the grain size reference in phase α and β brass alloys.



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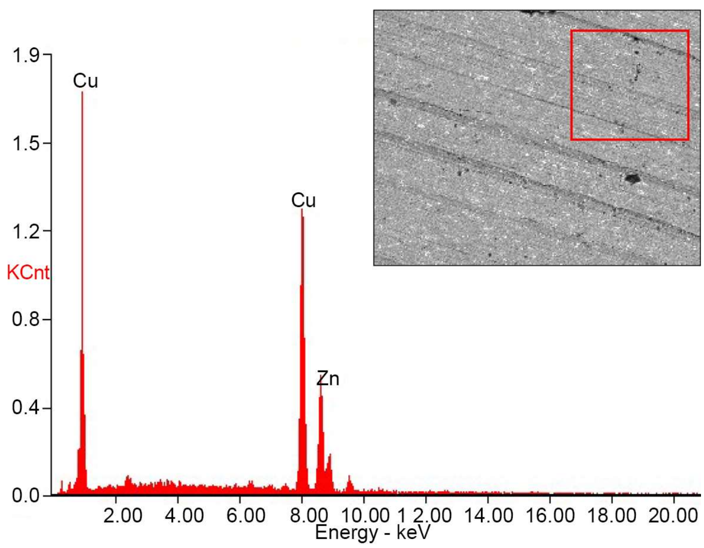

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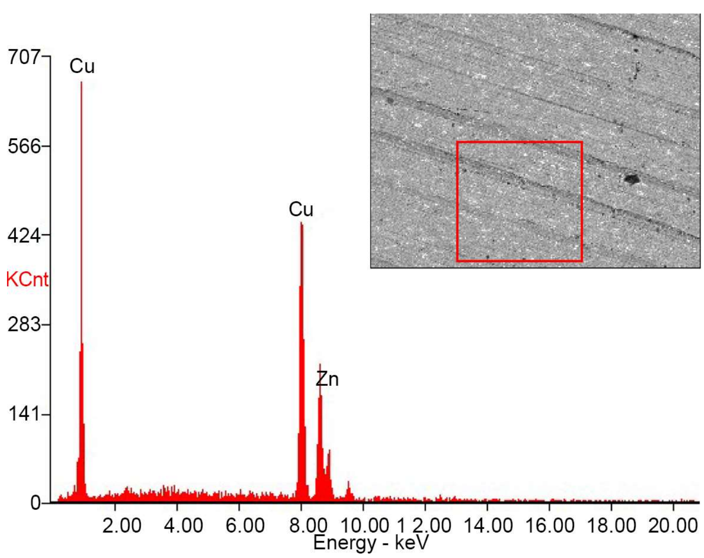
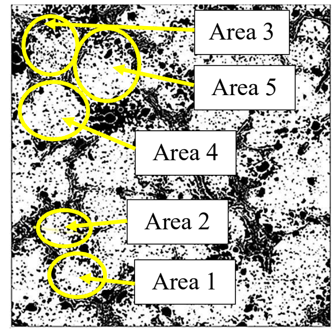


c

Fig. 4. SEM-EDX test results on 3 areas: *a* – area 1; *b* – area 2; *c* – area 3



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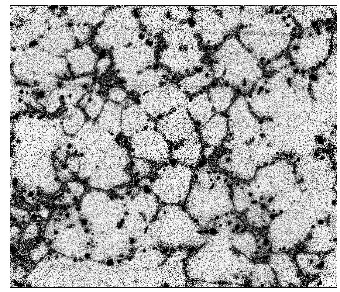

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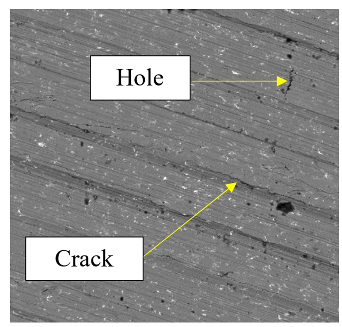

c

Fig. 5. Microstructure of the recycled brass alloy: *a* – microstructure with 100x magnification; *b* – area grain size measurement; *c* – surface defect cracks and holes with 50x magnification

Table 3

Grain size of the recycled brass alloy

Sample	Grain size (μm)
Area 01	22.42
Area 02	21.85
Area 03	26.85
Area 04	29.09
Area 05	30.13

Tensile strength testing produced a minimum value of 161.8 MPa and a maximum of 225.2 MPa, for a minimum yield strength of 144.2 MPa and a maximum of 179.8 MPa, the lowest elongation was 2.68 %, and the highest was 7.32 %. Details of tensile test results can be seen in Table 4.

From the table above, the average recycling yield of the alloy for ultimate tensile strength (MPa) is 203.9 MPa, yield tensile strength (MPa) is 164.8 MPa, and elongation is 5.76 %. Details can be seen in Fig. 6.

In Fig. 6, it can be seen that the ultimate tensile strength value of the finished product of CAC 302 far exceeds the result of casting recycled brass alloys. Fig. 7 shows the trend of differences in elongation values based on industry specifications and the results of this study.

Table 4

Strength of the recycled brass alloy

Sample	Ultimate tensile strength (MPa)	Yield tensile strength (MPa)	Elongation (%)
1	225.2	170.6	7.32
2	161.8	144.2	2.68
3	224.7	179.8	7.28

In Fig. 7, the comparison can be seen that the extension value of CAC 302 far exceeds the results of casting of recycled brass alloys.

The details can be seen in Fig. 8 below, describing the trend of *Ra*, *Rq* and *Rz* values of the specimens tested for roughness.

The trend of roughness of each specimen shows not much different values in each of the arithmetic average roughness (*Ra*), root mean square roughness (*Rq*), and ten-point height of irregularities (*Rz*) values of brass alloy recycling castings.

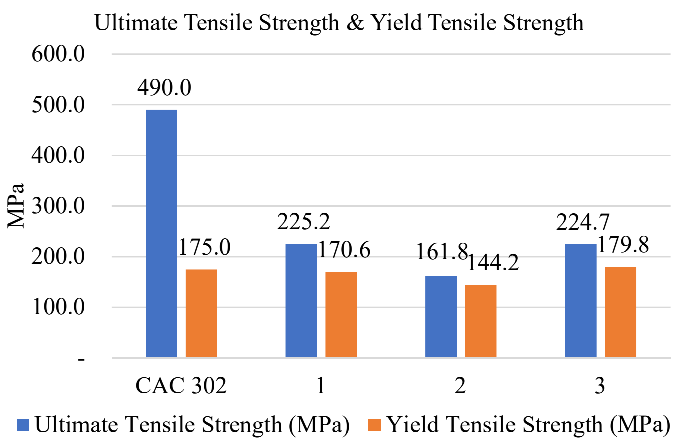

Fig. 6. Comparison of the tensile and yield strength of recycled brass alloys and CAC 302 gear materials

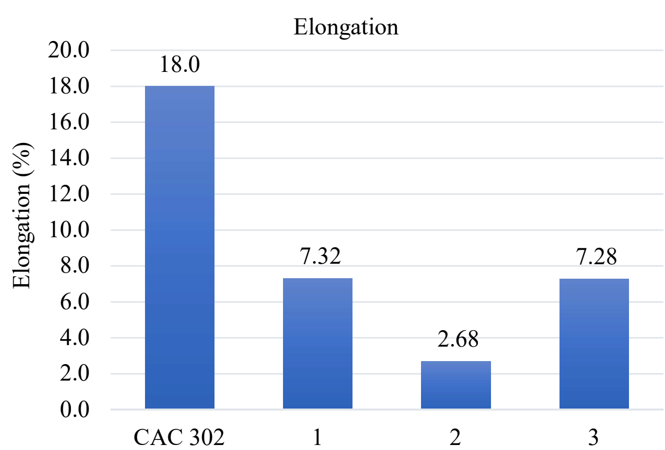

Fig. 7. Comparison of the elongation percentage of recycled brass alloys and CAC 302 gear materials

The conditions of applying these results provide an overview of the influence of slag, which will impact the quality of the casting results, element composition, grain size, and roughness that affect the characteristics and mechanical properties of recycled brass alloys in applications for gear materials.

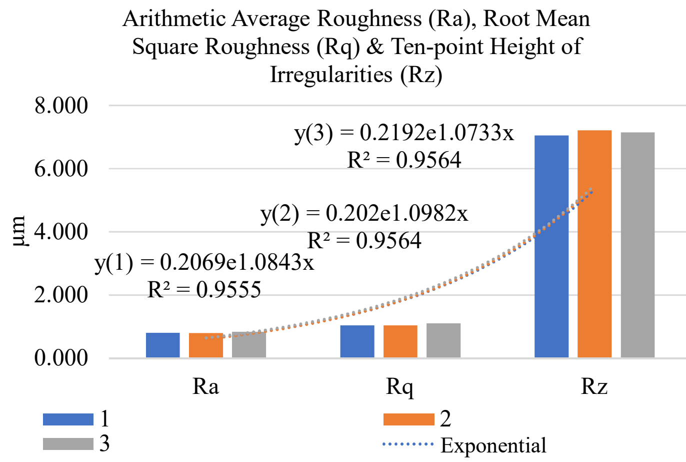

Fig. 8. The relationship between the arithmetic average roughness (*Ra*), root mean square roughness (*Rq*), and ten-point height of irregularities (*Rz*) values of brass alloy recycling castings

6. Discussion of the brass alloy recycling experiment and alloy mechanical property test results

The research objective is to produce recycled brass products that have competitive quality and are environmentally friendly. Recycled brass alloy melts at 526 °C up to 900 °C within 1 hour, and the casting process is carried out below the melting point of the brass alloy at 1,090 °C. This proves that smelting energy savings can be reduced by controlling temperature reduction. This has potential to be an efficient activity for energy consumption. The initial weight of the recycled brass alloy is 2,492 g, with the amount of slag being 144 g, so the final weight of the recycled brass alloy is reduced by 2,348 g. The amount of slag will affect the casting material's quality and the final weight because the slag is discarded during the process. The influence of the amount of slag produced reduces the initial weight by 5.77 %. The relationship of the amount of slag is as much as 5.77 %, as stated in Table 1.

The composition of elements in area 1 for Cu was 69.03 %, with Zn of 30.97 %. In area 2, there was a decrease in Cu elements to 68.27 %, but there was an increase in Zn elements to 31.73 %. In area 3, there was a decrease in Cu elements to 68.05 %, and Zn increased to 31.95 %, as stated in Table 2. So, there is an influence on the weight percentage of Cu elements that increasing will decrease the weight percentage of Zn elements, and decreasing the Zn content will decrease the strength of the brass alloy.

On the surface of the recycled brass alloy casting, there are cracks and holes at 50x magnification. Reducing the occurrence of scratches and cracks can be done by increasing the melting temperature to reduce friction between the melt surface and the mold [14, 21]. There is potential to reduce defects through increased temperature, but keeping the casting process's temperature below the brass alloy's melting point is necessary.

From the results of microstructure testing, the grain size for recycled brass alloys averaged 26.06 μm. From the reference, the average grain size was 25 μm in the α and β phases [15]. The grain size of recycled brass alloys is slightly larger than average in general, evidenced by the yield tensile strength value, which is not much different. Validation of the tensile strength, yield strength, and elongation results of recycled casting brass alloys was carried out by comparing with gear manufacturer specifications for high-strength brass castings (CAC 302) [14, 22], including the tensile strength of recycled brass alloys is a maximum of 225.2 MPa. Validation of the test results is required to confirm the results of the experimental test with the test results of the existing product until the laying alloy is used [22, 23]. The material specifications for CAC 302-type gears are 490 MPa or less than 53.97 %. For yield strength, the recycled brass alloy has a maximum of 179.8 MPa, exceeding the specifications of CAC 302, which is 175 MPa, and the excess yield strength is 2.74 %. The data is illustrated in Fig. 6. Comparison of the tensile and yield strength of recycled brass alloys and CAC 302 gear materials, and Fig. 7. Comparison of the elongation percentage of recycled brass alloys and CAC 302 gear materials.

The elongation specification for gear products by CAC 302 is 18 %, and the elongation test result of the recycled brass alloy is a maximum of 7.32 %. Material engineering is still needed to increase 59.33 % of the elongation achieved from the brass alloy recycling casting process. Details can be seen in Table 4. The strength of the alloy can still provide a good yield tensile strength value, but the ultimate tensile strength and elongation values still need to be improved.

The roughness level of the recycled brass alloy, the Ra value (average roughness), is between 0.802 µm and 0.836 µm. The *Rq* value (root square mean roughness) is between 1.037 µm and 1.103 µm. The *Rz* value (maximum height) is between 7.058 µm and 7.212 µm. Fig. 8 shows a relationship between the results of regression analysis of the arithmetic average roughness (Ra), root mean square roughness (*Rq*), and ten-point height of irregularities (*Rz*) values of brass alloy recycling castings. An increase in the value of *Ra* affects the increase in the value of *Rq* and *Rz*; a low value of roughness will reduce friction, excessive contact and noise on the gears.

A significant influence of the roughness level of *Ra*, *Rq*, and *Rz* from the results of recycled casting brass alloys is evidenced by an exponential regression value close to 1. The average roughness value of *Ra* is 0.815, which is still in the range of brass alloy surface roughness level of 0.63 µm~2.25 µm, as illustrated in Fig. 8. The relationship between the arithmetic average roughness (*Ra*), root mean square roughness (*Rq*), and ten-point height of irregularities (*Rz*) values of brass alloy recycling castings, so that there is a strong influence on the increase in the value of *Ra*, *Rq* and *Rz*. The results of this study provide an alternative solution, namely that the recycled brass alloy has the potential to become a quality, efficient, and environmentally friendly product.

This research contributes to producing environmentally friendly brass alloys through the recycling process by casting and producing alloys with good mechanical properties to be applied as gear materials or for other industrial needs.

The limitation of this study is that brass alloy waste is recycled from only one industrial source, so analysis of scrap coming from various types of industries is needed. The number of specimens needs to be increased to be tested for other mechanical properties such as hardness and wear rate of recycled brass alloys.

Further research can be carried out by recycling brass alloys by adding other metal elements to the composition, such as nickel, manganese, and aluminum, to improve the material's mechanical properties, especially its tensile strength and elongation.

7. Conclusions

1. The research results prove that recycled brass melted by investment casting has the potential for fabrication with temperatures below the melting point and has mechanical properties such as yield strength and roughness that are close to new materials from brass compared to existing products. This research produces the quality of recycled brass materials through an efficient and environmentally friendly process that can meet the industry's needs.

2. Recycling brass alloys from the EDX test results on Cu content produced an average of 68.05 % and Zn 31.95 %. The increase in the composition of Cu and Zn affects the casting result's quality and the material's mechanical properties. Recycled brass alloys have good yield strength and can be applied to engine element materials such as gears. Recycled brass alloys have an average tensile strength of 203.3 MPa and an elongation of 5.8 %, which is still below the industry specification standard for gear materials. The average surface roughness value (*Ra*) of 0.815 µm still meets the limit of the general roughness level of brass alloys.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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