An improvement of manufacturing process using 3D printing technology for overhead line components on railway electrification

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Abstract
In an electric railway, an overhead contact system (OCS) is assembled with many components, and it maintains a voltage of 25 kV to supply electricity to the electric trains. As electric trains grow faster, the overhead line comes to employ a diverse range of materials to deliver electricity and maintain high tension. Overhead lines supply electricity to electric trains through mechanical contact with a pantograph, and since they are not fault-tolerant, they require high reliability. That makes it take a long time to develop and supply components and also makes it difficult and time consuming to apply new materials or new designs to components. This study proposes a manufacturing process for overhead line components using 3D printing technology. For this, a clevis terminal clamp for high-speed railway was chosen and a design drawing was created with 3D scanning. For molding, additive manufacturing technology was used. The study castings were obtained by applying precision casting and sand mold casting methods, respectively, and their elongation and tensile strength were compared with products made with a traditional method.

Keywords 3D printing technology · Clevis terminal clamp · Overhead line components · Railway electrification

1 Introduction
With the rising speed of electric trains, an overhead line with a maximum speed of 400 km/h was developed in Korea [1]. Due to this rise of speed, stable current collection is required between pantograph and overhead line, and the tension of contact wire with the maximum speed of 400 km/h increased to 34 kN [2]. The increase in speed and tension of the overhead line can lead to a rise in the uplift amount, strain, and contact loss, which necessitates the development of components with high mechanical strength and electrical conductivity [3]. The overhead line system is installed at a height of 5 m or higher and consists of diverse components [4–6]. Especially, as the speed of railway increases, the demand for precision also keeps rising [1]. With the continuous increase of railway electrification, the improvement of durability and maintainability is required along with the need for changes of configuration and materials. However, overhead line components are usually manufactured according to system design conditions, which makes it difficult to change shape and materials of components and consequently to respond to problems arising during operation [7]. In addition, in the development of new overhead line components, high safety is required to meet technical standards, and it is also important to establish reliability by testing them on commercial lines and proving compatibility between components [8]. For this end, design suitability review and various reliability verifications should be conducted, which contributes to lowering economic feasibility and delaying production time [9]. Extreme cold and heatwave due to climate change also requires diversification of operating conditions of overhead lines. Thus, to simplify manufacturing process and quickly respond to design suitability, development of new technology is essential.

This study proposes a simplified manufacturing procedure and technology of overhead line components by using 3D printing technology. To verify the proposed procedure, a 3D CAD model was developed and designed for 3D printing. This 3D model was molded for casting with 3D printing and casted into a complete product. Furthermore, for precision
casting, a wax version was created with 3D printing, and mechanical characteristics were compared with sand mold cast version.

2 3D Modeling of overhead line component

2.1 Development of 3D CAD Model

This study analyzes the manufacture and characteristics of 3D printing for a clevis terminal clamp. The clevis terminal clamp for overhead lines is a key component used to connect dead-end points to anchoring, such as contact wire. Figure 1 shows the shape of the clevis terminal clamp [10].

Figure 2 shows the 3D CAD result of the clevis terminal clamp performed. To create a 3D CAD file, the drawing that was designed as per the specifications of the Korea Rail Standard Authority was converted into a CATIA template model based on CATIA V5 knowledgeware and compared with 2D drawing.

A solid model can be used for CAD and CAM. In this study, it was converted into a standard triangulated language (STL) file, which is a rapid prototype for sand mold casting.

2.2 Rapid manufacturing Process for injection molding (die casting operation)

A 3D printer used to make a sand mold for the clevis terminal clamp was a binder jetting printer manufactured by Voxeljet with manufacturing capacity of 1000 × 600 × 500 mm. To make a sand mold, thousands of layers were pre-defined and sand was prepared. Sand particles were spread on the cross-section and coated with a binder over and over again until a final object is complete. After a liquid binder is selectively sprayed on a bed of sand power, the bed goes down one layer below. This process consisting of spraying sand and binder is repeated. For this, silica sands of various grain sizes were used. The binder type was phenolic resin with binding strength of 220 N/cm² or higher. Figure 3 shows the manufacturing process of the clevis terminal clamp using binder jetting method. The sand mold casting plan and mold design were developed using a 3D CAD file. Then, a mold was manufactured using a binder jet 3D printer. The process of spraying sand particles and binder was repeated layer by layer. Prior to casting, filling and solidification behaviors were predicted based on interpretation of injection and solidification of casting material, and analysis on riser, gating, and mold design was conducted for the development of cast design and implementation plan. To prevent damage and alteration of material, the inner wall of mold was coated with molding wash, and after assembling the upper and lower molds, moisture was removed and then a molten metal was injected. Figure 4 shows the manufacturing process of the clevis terminal clamp using precision casting. For precision casting, the lost-wax version of clevis terminal clamp was made using the stereolithography apparatus (SLA), and then cast through ten shell coats. Unlike precision casting, the 3D-printed sand mold as shown in the figure does not require mock-up, mold design, or manufacturing process. But, the dimensions may change, so an analysis for them was carried out.

3 Performance verification of clevis terminal clamps made with 3D printing

3.1 Manufacturing result of the clevis terminal clamp

Overhead lines are assembled with many components, so high reliability is required in regard to manufactured tolerances. For this reason, the precision casting is generally used [10, 11]. However, the current precision casting for overhead line components requires a relatively
long time compared to sand mold casting since it takes longer to design and verify molds or dies and it requires the additional manufacture of a wax pattern. To determine the dimensional accuracy, the dimensions of sand molds made with 3D printing and the dimensions of lost-wax version made with precision casting were compared. Figure 5 shows the 3D scanning results of clevis terminal clamps manufactured with precision casting (lost-wax casting) and sand mold casting, respectively. The 3D scanner used for the precision test was AICON’s SmartSCAN. With two Color CCDs with the pixel of 3296 × 2472, this scanner works based on interference pattern and offers the measurement precision of 8 μm. The consistency of precision between precision casting and sand mold casting was evaluated by comparing the 3D scan results with the specifications set forth 3.2-dimensional tolerance for the clamp in KRSA-3029-R3 of the Korea Rail Standard Authority. As seen in the figure, the positions of precision casting and sand mold casting appear different. But the data alignment position is the same even if the extracted values in the 3D images are different. In the figure, sand mold casting and precision casting have minus values, which are smaller than the designed values. It was thought that it was due to the manufacturing process or manufacturing tolerance during the casting process [11].
The tolerance of the clamp varied from position to position, but the minimum tolerance was 0.5 mm. Figure 6 shows the histogram for the tolerance section of ±0.5 mm along with the percentage of consistency. Based on the precision evaluation results obtained by comparing random points for the precision cast based the clamp using lost-wax, the consistency was 96.29% with a mean of −0.18 mm and a standard deviation of 0.2143 mm. And the results of histogram analysis of the clamp made with a sand mold showed that the consistency was 81.22% in the allowable tolerance section of ±0.5 mm, with a mean of −0.2406 mm and a standard deviation of 0.2868. The error rate was believed to

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**Fig. 5** 3D scanning results of a clevis terminal clamp manufactured with precision casting (lost-wax) and sand mold casting

**Fig. 6** Histogram results of clevis terminal clamps of front and rear surface
be higher than that of precision casting due to a decrease in volume caused by drying process.

For future works, it should be taken this into consideration. This histogram graph illustrating the frequency distribution for the consistency of 3D scanning data indicates that the precision casting based the clamp has a higher precision than the sand mold casting based the clamp. However, the dimensional accuracy in precision casting and sand mold casting showed the allowable error of less than 0.5 mm, suggesting that two methods are both suitable for manufacturing overhead line components, and will contribute to minimizing dimensional errors. On the other hand, if the 3D printing technology is used, there may occur a dimensional discrepancy with existing products. Given this, it will be necessary to develop technology that can determine whether the allowable errors are met in the installation and assembly.

### 3.2 Results of mechanical properties of a 3D printing

Figure 7 illustrates the tensile test bar for clevis terminal clamps using 3D printing sand molding. The metal part of the clamp is 33 mm in diameter and 106 mm in length, and made of a copper–aluminum alloy, including Al, Fe, Ni, and Mn. In particular, the copper–aluminum alloy used for overhead line components is 90% Cu, and Al is combined for high strength. Fe, Ni, and Mn are added to improve strength, and Mg, Zn, Si, Sn and Pb are contained in small amounts. When manufacturing the clamps using 3D printing sand mold casting proposed in this paper, in particular, changes in the chemical composition may lead to changes in the mechanical properties such as strength and elongation, thus requiring analysis.

The chemical composition of the overhead line components is an important indicator that determines the mechanical and electrical properties of material. This study analyzed the chemical composition of the copper–aluminum alloy and evaluated the mechanical and electrical properties. Table 1 shows the chemical composition of the material used to manufacture the clamp.

The analysis results can be used for determining material for overhead line components based on the mechanical and electrical properties of material. The clamp using sand mold casting method was analyzed for chemical composition ratio with an optical emission spectrometer. For this chemical analysis, an optical emission spectrometer that could conduct quantitative and qualitative analyses for inorganic elements of metals and nonferrous metals was used. It has a focal length of 750 mm and 2400 grooves mm, and the detector employs photomultiplier tubes. The Channels (38ea Channels) can detect steel/Al/Cu/Ni alloys. As shown in Table 1, two different compositions were used. The #1 material was comprised of 84.72% of Cu and 10.29% of Al, followed by Fe, Ni, and Mn. The composition was similar to the general composition ratio of CuAl10Fe2. The #2 material showed the properties of the ALBC2 series, with a composition of 84.42% of Cu, 9.82% of Al, and 2.95% of Fe. Mg was not detected. Both #1 and #2 had similar composition ratios of Cu, but the #1 material contained a higher content of Al; whereas the #2 material contained somewhat higher content of Fe and Mn.

Table 2 demonstrates the mechanical properties based on the composition ratio of the copper–aluminum alloy series. For both #1 and #2 materials, the same materials were used to manufacture specimens for sand mold casting with 3D printing and lost-wax casting as the precision casting. To investigate mechanical properties, tensile strength, yield strength, elongation, and Brinell hardness were measured.
4 Conclusion

In the electric railway, overhead line components require mechanical properties suitable for a stable supply of electricity to electric vehicles and tensile and fatigue properties caused by pantograph impact. However, to meet the demand for their distinctive characteristics, small scale and emergency repair, it is necessary to develop technology for a new manufacturing procedure that can reduce the manufacturing time and improve the quality of material.

This paper proposed a sand mold casting technology applied with 3D printing method for the production of components of overhead lines for the electric railway. For production of overhead line components using 3D printing, the clevis terminal clamp for high-speed railway was designed through 3D CAD, and then converted into an STL file, a rapid prototype for sand mold production, before being applied to the manufacturing process. For making a sand mold, Binder jetting method was used, and changes in production dimensions were analyzed using a 3D scanner. Based on the results of dimensions of the clamp manufactured with a sand mold using 3D printing, measurement values were lower vs a 3D model due to drying process and a reduction in volume. But it was possible to manufacture clamps fast by using 3D printing within the range of allowable errors. To analyze the chemical and mechanical properties of the clevis terminal clamp, two specimens were manufactured, and changes in their chemical composition and mechanical properties were measured. The tensile strength and elongation varied depending on the composition ratio of Al and Fe.

The study demonstrated that the manufacturing technology of overhead line components using 3D printing and a sand mold, as proposed in this study, could reduce the time required for manufacturing and changing the design. However, to meet the high standard for mechanical property for overhead line components, additional experiments will be needed with regard to heat treatment or composition change of material after manufacturing. The procedure and technology for manufacturing overhead line components using 3D printing proposed in this paper will be able to be used for reducing the manufacture time, developing new materials and shapes, and conducting urgent maintenance work for overhead line components.

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