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# Development of magnetic pulse crimping process for high-durability connection terminal

Ji-Yeon Shim*, Bong-Yong Kang**
*( Carbon&Light Materials Application R&D Group, KITECH, Korea*
** Carbon&Light Materials Application R&D Group, KITECH, Korea*

## ABSTRACT

Generally, hand-operated and hydraulic compressors use crimping of connection terminals. However, this equipment often causes compressed defects because non-uniform pressure is applied in the circumferential direction of the terminal during crimping. A defective terminal often leads to fire in electric equipment due to overheating. Therefore, there is a need to develop a new crimping process for manufacturing highly durable terminals. MPC (magnetic pulse crimping) uses uniform electromagnetic pressure by a high magnetic field interaction between coil and terminal. This process uses only electromagnetic pressure for crimping, so the terminal can be crimped without physical contact, thereby producing a highly durable connection terminal. In this study, a MPC process was developed to fabricate a prototypical terminal. The result was compared with other crimping processes in terms of durability. The crimped part using MPC has a lower rising temperature and higher tensile strength than those using other crimping process. It is inferred from the experimental results that an optimal charging voltage exists in the MPC process

***Keywords*:** MPC(Magnetic pulse crimping process), Connetion terminal, Electromagnetic force

## I. INTRODUCTION

The connection terminal is an essential component of electrical equipment, given that it plays a vital role in sending a current from the main power supply. Generally, copper or copper alloy – each of which has high electrical conductivity -- is used as a connection terminal. Hand-operated and hydraulic compressors with electric motors are used for crimping of connection terminals and cables. However, this equipment uses non-uniform pressure in the circumferential direction for crimpling, so the crimping part of the terminal with the inner wire will often have many defects. When the terminal is connected to electrical equipment, a low crimping force causes the terminal to separate from the inner wire, and a low wire density in the terminal often leads to fire due to overheating. Moreover, a compressed defect causes wear due to high temperature and electrical corrosion, which, in turn, shortens the lifespan of the connection terminal [1-4]. Therefore, these defects drive up manufacturing costs of the complete product. In particular, overheating in the terminal crimping part is not only an unstable supply of current – resulting in a decrease in manufacturing production efficiency -- but also causes sparks on electrical equipment, thereby threatening workers' safety. However, the development of crimping process for manufacturing the high- durability terminal has been nearly carried out.

Therefore, the objective of this paper is to develop the MPC process for manufactured high-durability connection terminal. In order to carry out this, MPC system consisting of a pulse power source, crimping coil, and jig system were utilized. After manufacturing the prototypical connection terminal, temperature variation and tensile strength were measured and compared the results with crimping parts using hand-operated, hydraulic compressors for verifying durability. It is anticipated that this research will contribute to improve the durability of terminal using MPC process.

## II. MPC PROCESS

MPC is a high-speed crimping process using an electromagnetic force that causes a high-velocity compression on two workpieces. Here, these two workpieces are the terminal and inner wire; a MPC system that consists of a pulse power source, crimping coil, and loading and unloading system [5-7]. The workpieces are inserted into a crimping coil, so they overlap with each other as shown Fig. 1. When a high pulse current from the power source passes through the crimping coil, a high magnetic field is instantaneously generated around the coil. At this point, an eddy current is induced on the outer workpiece surface. The induced eddy current flows in the opposite direction of the working coil, which produces a high electromagnetic force. This electromagnetic force is applied on the outer workpiece, leading to compression with the inner workpiece at nearly 1000 m/s [8].

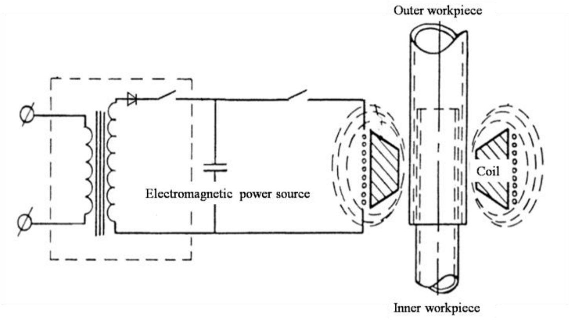


**Fig. 1** Schematic illustration of the generation of an electromagnetic force [5]

Here, a pulse power source (WELMATE CO.,LTD) that can be charged up to 14 kV, so the maximum charging energy is 60 kJ. Specifically, the crimping coil is directly related to the crimping part quality, so the development of the crimping coil is very important to the overall MPC system. However, a theoretical analysis for the development of optimum crimping coils, considering various factors, has not yet been performed. Nevertheless generally the considered factors can be classified into geometric, mechanical, and electrical properties of the material.[9-11]

The crimping coil material should allow for electrical and mechanical properties such as conductivity to prevent damage to the condenser due to the duration of the magnetic field or sudden discharge [12-13]. It should also provide strength to prevent repulsive forces during crimping. Therefore, copper, aluminum and beryllium-copper have been considered as materials for the crimping coil, and beryllium-copper has been selected in this study. Fig. 2 shows the design of the crimping coil with a terminal.

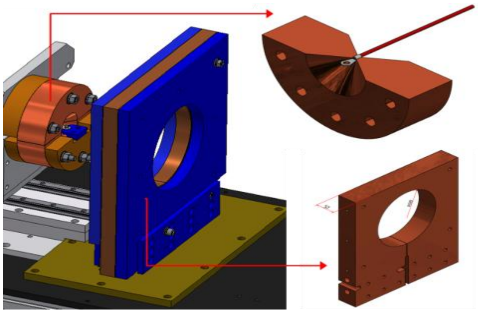


**Fig. 2** Designed crimping coil

A one-turn crimping coil has a field shaper for concentration of electromagnetic interaction. The field shaper is bifurcated for inserting the terminal. The MPC process was initiated by inputting the terminal into a separated field shaper. Then, the field shaper traveled toward the one-turn coil, pushed by the hydraulic compressor using an electric motor. After set-up, the voltage was charged on a pulse power source, and then discharged within microsecond to the crimping coil.

## III. EXPERIMENTAL WORK

### 3.1 Experimental procedures

The experimental workpieces were employed the C12200 terminal with a 1.2 mm thickness, 8 mm diameter. Materials surface subjected to clean with alcohol and dried. No special surface treatment was made before crimping. Prepared terminals were inserted into the crimping coil and overlapped by 10.5 mm in length. In particular, the gap of the terminal -- the outer workpiece with high electrical conductivity and a crimping coil – was consistently maintained at 1.0 mm for highly electromagnetic interactions. Fig. 3 shows the set up for MPC process.

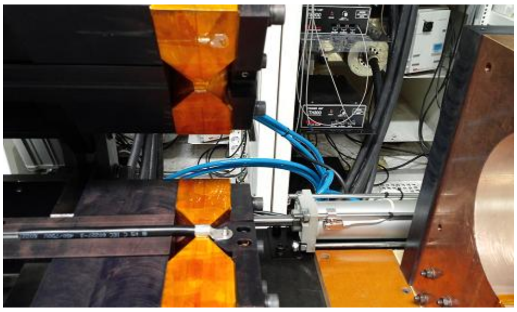


**Fig. 3** Set-up for the MPC

The Rogowski coil for measuring the currents during the discharge time was set at the connection between the pulse power source and crimping coil. The Rogowski coil can measure the current linearly, from low current to high current, using mutual inductance, and can measure the current within a wide frequency range.

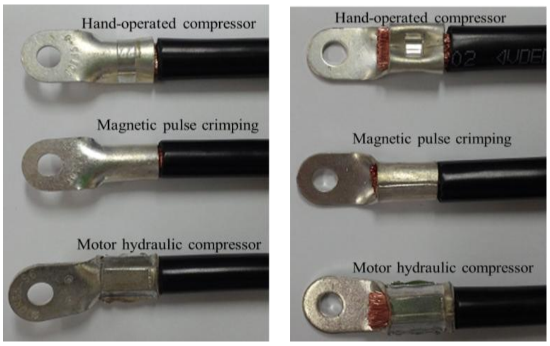
For MPC, the charging voltage was selected as 6 kV 7 kV 8 kV and 9 kV, with a corresponding electrical energy of 8 kJ, 11 kJ, 15 kJ and 19 kJ, respectively. After crimping, the crimping part was evaluated by comparing with that using a hand-operated compressor and hydraulic compressor. The temperature rise test and tensile test were carried out as shown in Fig. 4.

(a) Tensile test (b) temperature rise test

**Fig. 4** Evaluation test of the crimping part

### 3.2 Experimental procedures

Fig. 5 shows the crimping part by MPC, a hand-operated compressor and hydraulic compressor, respectively. When using the hand-operated compressor for crimping, a terminal was crimped by applying non-uniform pressure to the terminal, so the rear side of the terminal was distorted. When the terminal was crimped using a hydraulic compressor, hydraulic pressure damaged the surface of the terminal and significantly distorted the crimping part. In contrast, the MPC-crimped terminal never damaged the surface or distorted the terminal. Since electromagnetic pressure was applied uniformly on the surface of the terminal, the process neither distorted the terminal nor damaged the surface of the crimping part.



(a) Front (b) Rear

**Fig. 5** Terminal crimping

Fig. 6 shows the results of the temperature rise test with 3 types crimping processes in a 32 ℃ room. When a 30 A current was continuously sent through the crimped terminal using the 3 types of crimping processes, temperature rose continuously. After 10 minutes, the temperature rise of the crimped terminal using MPC with 8 kV charging voltage was approximately 18.5 ℃. However, the surface temperature using a hydraulic compressor was approximately 20 ℃; whereas, the surface temperature of the crimped part using a hand-operated compressor was 23 ℃. Over time, this temperature difference increased, and after 100 minutes, the surface temperature of the terminal using a hand-operated compressor was 51 ℃. Additionally, the surface temperature of the terminal using a hydraulic compressor was 44 ℃, and the surface temperature of the terminal using MPC was 38 ℃. The reason for this is the increase of wire density in the terminal using MPC.

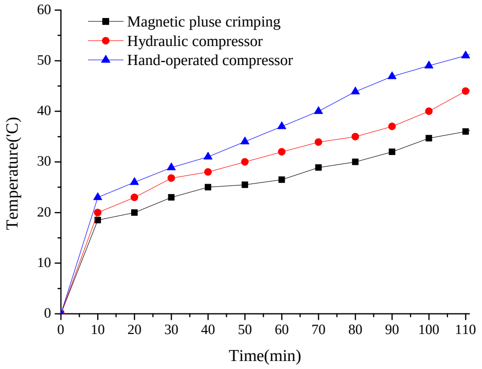


**Fig. 6** Result of a temperature rise test

When a 30 A current was continuously sent through the crimped terminal using the 3 types of crimping processes, temperature rose continuously. After 10 minutes, the temperature rise of the crimped terminal using MPC with 8 kV charging voltage was approximately 18.5 ℃. However, the surface temperature using a hydraulic compressor was approximately 20 ℃; whereas, the surface temperature of the crimped part using a hand-operated compressor was 23 ℃. Over time, this temperature difference increased, and after 100 minutes, the surface temperature of the terminal using a hand-operated compressor was 51 ℃. Additionally, the surface temperature of the terminal using a hydraulic compressor was 44 ℃, and the surface temperature of the terminal using MPC was 38 ℃. The reason for this is the increase of wire density in the terminal using MPC.

Fig. 7 shows the result of a tensile test with 3 types of crimping processes. The tensile strength was measured at 2.9 kN, 2 kN and 1 kN using MPC, a hydraulic compressor, and a hand-operated compressor, respectively. The tensile strength of the crimped part using MPC was higher than that using the hand-operated compressor. This indicates that the crimping strength was improved when a highly uniform electromagnetic force with a high velocity was applied to terminal. Furthermore, the temperature rise test and tensile tests confirmed that the MPC was the most effective method for crimping the terminal, and can achieve a highly durable terminal. For analyzing the effect of the charging voltage using the MPC process, a charging voltage was varied from 6 kV to 9 kV, and a waveform was obtained using a Rogowski coil, as shown in Fig. 8.

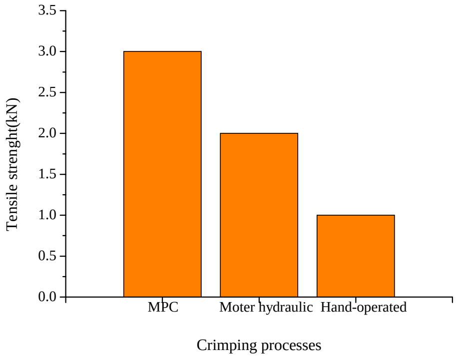


**Fig. 7** Result of the tensile test

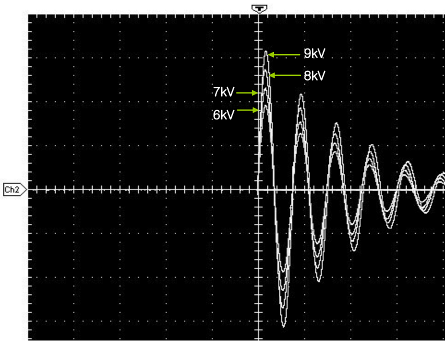


**Fig. 8** Waveform (X:100μs/div, Y:50kA/div)

The damped sinusoidal waveform was measured and the discharging time to peak current was 20 μs in all MPC conditions. The peak currents increased in direct relation to the charging voltage, and each of the measured currents was 95 kA, 115 kA, 135 kA and 158 kA at 6 kV, 7 kV, 8 kV and 9 kV, respectively.

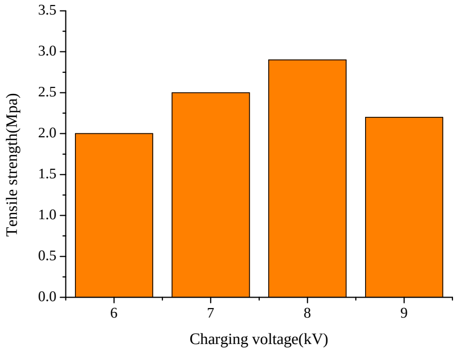


**Fig. 9** Result of the tensile test with various charging voltage

The tensile strength was increase as increasing the charging voltage as shown Fig. 9. However, the tensile strength was decreased at a charging voltage larger than 9 kV, due to the fact that the terminal was compressed to the inner wire by a highly electromagnetic pressure with a high velocity, cutting the inner wire. Cutting the inner wire resulted in a decrease of the tensile strength. Accordingly, it is inferred that optimal charging voltage exists around 8 kV. From these results, it confirms that MPC process can achieve a highly durable crimped terminal, which can result in a decrease of manufacturing costs and safety accidents.

## IV. CONCLUSION

A terminal was crimped using a MPC. The crimped part was compared to that of a hydraulic compressor and hand-operated compressor, respectively, and the following conclusions were generated:

(1) A crimped terminal had no surface damage or distortion using the MPC process, but surface damage and distortion was observed on the crimping part using the hand-operated compressor and hydraulic compressor because non-uniform pressure was applied directly to the surface of the terminal. However, the MPC process used a uniform electromagnetic pressure with no contact, so it could create a non-defective terminal surface.

(2) Three types of crimped parts were analyzed using a temperature rise test and tensile test. When current was continuously sent through the crimped terminal, temperature rose continuously, and the highest temperature was measured in the crimped terminal using a hand-operated compressor. The temperature difference between the MPC and hand-operated compressor was approximately 13 ℃, because applying a uniform electromagnetic pressure on the terminal led to an increase in cable density in the terminal, so the temperature was increased. Similarly, tensile strength was highest on the crimped part using EMF

(3) In the MPC process, tensile strength increased in direct relation to the charging voltage, but an exceedingly high electromagnetic pressure led to cut of the inner wire, so the tensile strength decreased. It is inferred that optimal charging voltage existed in the MPC process, and 8 kV was determined to be the optimal charging voltage for crimping the copper connection terminal with 1.2 mm thickness and 8mm diameter.

## ACKNOWLEDGEMENTS

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