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Applicability of Electrical Cables in Insulated Multi Core Tubes under the Supply of 15℃ Cooling Water

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15℃ 냉각수 공급 조건 단열 다심관의 전기케이블 활용 가능성

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Abstract

The International Maritime Organization has adopted the Polar code to strengthen safety regulations for vessels sailing in polar regions in response to the increasing demand for ships operating in polar regions worldwide. Furthermore, ongoing active research and development is being carried out in the field of electric propulsion ships to strengthen the response to emission control regulations in the maritime industry. Based on previous research, our research team determined that there is a need for various studies on insulated multi-core tubes developed as ship components for operating under extreme conditions. Therefore, we conducted an empirical experiment to utilize insulated multi-4-core tubes as electrical cables for ships. The durability and temperature changes of the cable were tested when DC current conditions of 10-25A were supplied in a stepwise manner to two cores of the multi-4-core tube and when cooling water was supplied at a level of around 15℃ and 13 l/min to the other two cores. At the minimum condition of 10A, the temperature of the core increased by 1.75℃, while at the maximum condition of 25A, it increased by 11.9℃, resulting in a temperature difference of approximately 10.15℃. However, the inlet-outlet temperature difference of the cooling water remained relatively uniform at approximately 0.7-1.0℃ under all conditions. This indicates that the established cooling water system operated with excessive flow rates. Thus, it was extrapolated that a higher cooling effect could be achieved if the heat exchange and residence time of the cores are maximized by appropriately reducing and adjusting the flow rate of the cooling water in the future.

Key words : Insulated multi core tube, Polar code, Glass wool, Electric propulsion ship, Over current, IMO

I. Introduction

Multi-core tubes (MCTs) refer to a combination of pipes or tubes of a metal material made into a single cable (Lee and Kim, 2019). MCTs are efficient components that can reduce maintenance and repair costs because they bind several pipes together to transport fluid and electrical energy in various applications, such as ships, plants, and buildings (Lee, 2016). These MCTs are mainly distributed abroad in several forms of products, and competition among manufacturers is expected to accelerate, but the competitiveness of domestic products is somewhat inadequate. Recently, the

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International Maritime Organization (IMO) has adopted the “International Code for Ships Operating in Polar Waters” (Polar Code) (Jung et al., 2019) as the possibility of polar voyages for ships is increasing. Thus, the demand for dedicated ships that can navigate the Arctic Sea and polar land plants will rise substantially (Kim and Park, 2017).

Therefore, there is sufficient demand and competitiveness in the development of insulated MCTs that can endure extreme environmental conditions. Thus, it is necessary to develop insulated MCTs that are suitable for extreme environmental conditions in the MCTs field that has traditionally relied on foreign technological expertise and to undertake various research efforts related to this (Lee and Kim, 2023).

Furthermore, propulsion systems of ships have recently transitioned from traditional internal combustion engines to electric propulsion owing to the acceleration of development in the field of electric propulsion ships. In light of this, our research team has determined that it is necessary to thoroughly examine the feasibility of utilizing the developed insulated MCTs as an electrical cable (Lee and Kim, 2023).

In a previous study, a multi-4-core tube using glass wool as insulation material was manufactured and developed, and research was conducted on the heat transfer characteristics under the condition of the hydraulic working fluid flowing through the tube and external air temperature ranging from -10 to 50℃ and analysed the insulation performance (Lee and Kim, 2019; Lee, 2016). The research team performed a study on the heat generation characteristics of the cable by supplying 25℃ cooling water and overcurrent as a preliminary investigation to verify the potential use of the insulated MCTs as an electrical cable (Lee and Kim, 2023).

Furthermore, in recent similar research trends related to insulated MCTs and electrical cables, pipe insulation materials were manufactured by applying furan composites (BFCs) to reduce the weight of the equipment for eco-friendly ships, and the mechanical strength and heat-resistant/ flame-retardant properties were tested and evaluated (Kwon and Seo, 2021). As opposed to extreme environmental conditions, several studies have been conducted to prevent the expansion of combustion in terms of safety because MCTs can provide a pathway for combustion expansion (Choi et al., 2002).

In addition, heat conductivity and heat discharge characteristics were analysed using cooling water on a 4-core cable of 70 mm in diameter to counteract the heating risk of wires due to high current rapid charging in electric vehicles. However, this is a case of numerical analysis based on CFDs, and the study of empirical experiments is somewhat insufficient (Ahn et al., 2019).

Moreover, a cable with a diameter of 0.8 mm and a length of 150 mm was analysed in the actual experiments using the DAS (Dendrite Arm Spacing) mechanism, and the upper threshold for interruptions and temperature increased due to overcurrent (Park et al., 2017).

Therefore, based on our team's previous research, we conducted experiments on the thermal and cooling properties of stainless-steel cores due to overcurrent change in conditions where 15°C cooling water is supplied using an insulated multi-4-core tube with a glass-coloured insulating material and determined the applicability of the isolated MCTs as electrical cable.

Ⅱ. Research Method

1. Manufacturing of MCTs

The technology related to MCTs originated in Germany and was being developed and commercialized by major Asian countries, including South Korea and China (Lee, 2016).

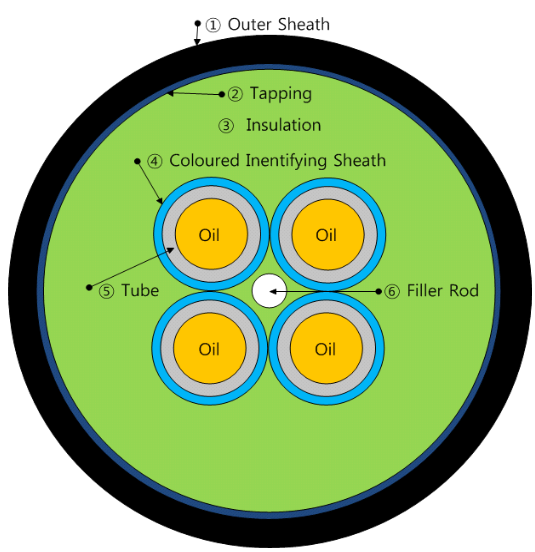
[Fig. 1] depicts the actual manufacturing process of MCTs and whereas illustrates the process of producing the product by coating it with a thin film of glass wool (Kim and Park, 2017; Lee and Kim, 2023).

[Fig. 1] MCTs manufacturing and insulation process.

The process of creating insulated MCTs comprises twisting and binding multiple stainless-steel pipes together, coating the surface, and sequentially performing processes such as using glass wool as insulation material and applying a PVC film. The manufactured product undergoes pressure leakage testing before being released as a finished product (Kim, 2009).

Typically, the material used for the core of a structure is stainless steel, which has high corrosion resistance and excellent workability (Lee, 2016). The selection of glass wool as an insulation material throughout the manufacturing process was made due to its superior sound absorption performance, durability at high temperatures, and fire resistance, making it suitable as the insulation material for MCTs (Kim et al., 2013).

<Table 1> lists the properties of the insulated MCTs produced in this study, and [Fig. 2] depicts the cross-section design of the multi-4-core tube (Lee and Kim, 2019; Lee, 2016; Kim and Park, 2017; Lee and Kim 2023).



[Fig. 2] Cross section for Insulated MCTs.

<Table 1> Material of insulated MCTs

No.	Section	Material	Thickness (mm)	Outside diameter (mm)	Density (kg/m3)	Cp (Specific heat) (J/kg·K)	Thermal conductivity (W/m·K)
①	Outer sheath	PVC	3	45.5	1470	840	0.1
②	Tapping	Nonwoven	0.75	39.5	80	1300	0.06
③	Insulation	Glass wool	10	38	24	700	0.038
④	Coloured identifying sheath	PVC	0.5	9	1470	0.184	0.1
⑤	Tube	SUS 316	1	8	8238	468	13.4
⑥	Filler rod	PVC	-	3	1470	840	0.1

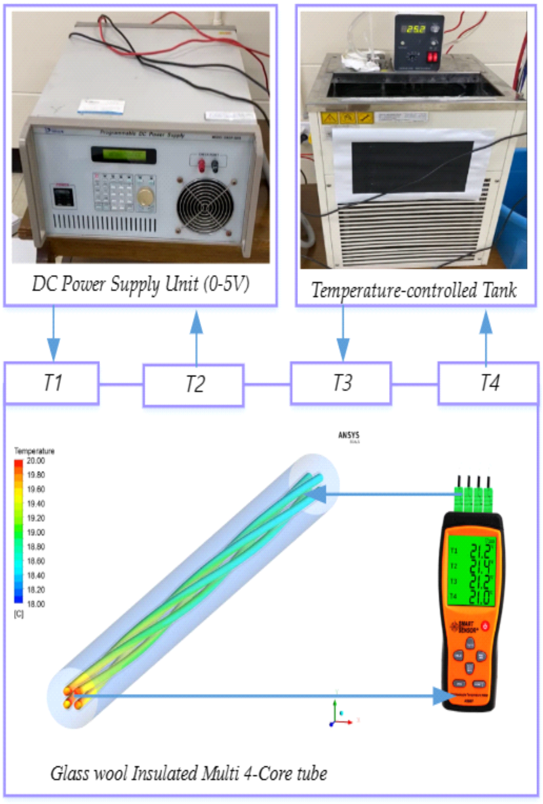
Source: Lee and Kim, 2023; Lee and Kim, 2019

2. Experiments according to the supply conditions of 15℃ cooling water

With the manufactured insulated multi-4-core tube, the DC current generated by the DC power supply was set to an overcurrent condition in the range of 10-25A for two cores. For the other two cores, a thermostatic tank that can be cooled and heated was used to circulate cooling water through the supply and discharge of cooling water at a room temperature of 15℃.

Under conditions of overcurrent and cooling water supply, temperature was measured at each inlet and outlet at intervals of 300 seconds over a period of about 1200 seconds, considering stability at the initial conditions.

Then, the accumulated data was analysed to assess heat generation and cooling effects in the tubes. <Table 2> present the supplied water-cooling conditions, physical properties, and brief experimental conditions. [Fig. 3] presents the schematic diagram of the experiment. In addition, the experiment did not consider the external ambient temperature and focused primarily on analysing the temperature changes and cooling effects at each location under the same conditions.



[Fig. 3] Experiment schematic diagram.

<Table 2> Experiment and cooling water conditions

List		Specification	Unit
Setting	Volt	5.0	V
	Ampere	10, 15, 20, 25	A
DC (+,-)		T1	°C
		T2	
Inlet water		T3	
Outlet water		T4	
Measurement time		1200	/sec
Density		997.1	kg/m^3
Specific heat		4.178	kcal/kg·°C
flow rate		13.0	ℓ/min
Inlet temperature		14.7-15.1	°C

remark : temperature-controlled tank is used to maintain a constant supply temperature of the cooling water.

Ⅲ. Results

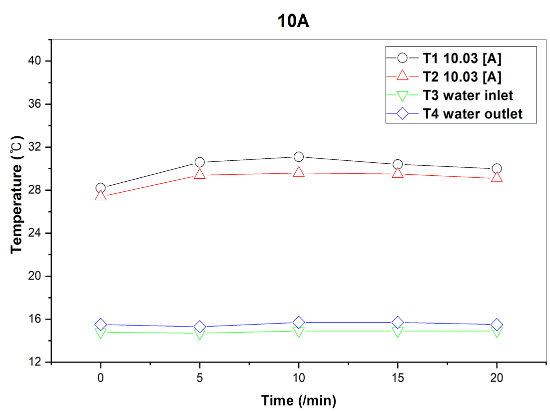
The present study compared the temperature increase in the insulated MCTs due to changes in the current flow with the effect of supplying cooling water at room temperature, as illustrated in [Fig. 4-7].

For the case of a setting value of 10A, the actual supplied current level was approximately 10.03A, causing the initial temperature of the core to increase by approximately 1.75℃ from 27.80℃ to 29.55℃.

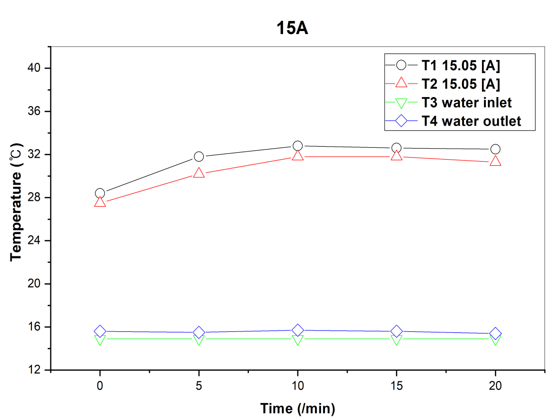
The maximum deviation in temperature absorbed and discharged by the circulating cooling water was approximately 1.0℃. When the actual supplied current under the condition of 15A was 15.05A, the initial temperature of the core increased by about 3.95℃, from 27.95℃ to a level of 31.90℃. It can be observed that the maximum deviation of the circulating cooling water is approximately 0.8℃.

The actual supplied current under the condition of 20A was 20.06A, and the initial temperature of the core increased by about 7.65℃, from 28.2℃ to 35.85℃. The maximum deviation of the circulating cooling water was 0.7℃.

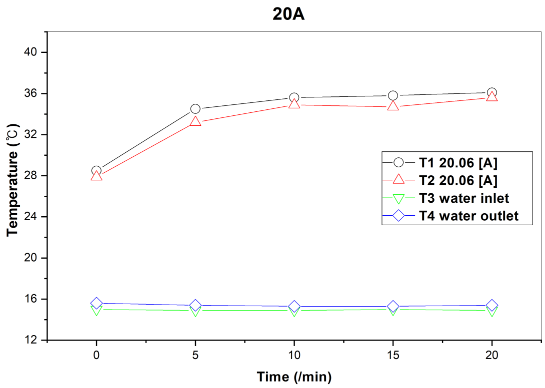
The actual current value under the maximum experimental condition of 25A was 25.08A, and the initial temperature of the core increased relatively high to 40.30℃, which is approximately 11.9℃ higher than other conditions when the initial temperature was 28.4℃. The maximum deviation of the circulating cooling water was 0.7℃.



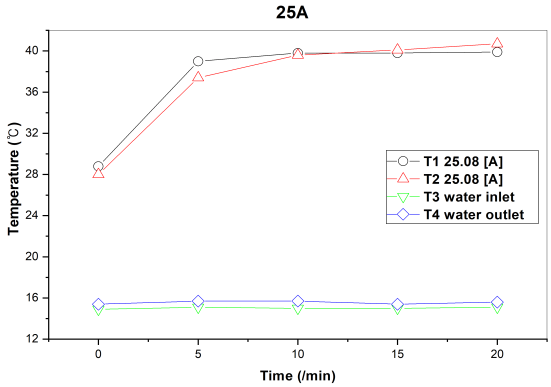
[Fig. 4] Result of over-current 10A conditions.



[Fig. 5] Result of over-current 15A conditions.



[Fig. 6] Result of over-current 20A conditions.



[Fig. 7] Result of over-current 25A conditions.

The cooling water deviation due to the increase in the supplied overcurrent was minimal for all four conditions, and a relatively consistent increase of 0.7– 1.0℃ was seen across all conditions.

[Fig. 8] presents a simplified comparison of the average temperature increase rate of the core and the effect of cooling water in response to changes in overcurrent conditions of the insulated MCTs. As the current flowing through the core increases, the actual temperature of the core increases proportionally, from 1.75℃ to 11.9℃, with a maximum increase of 10.15℃. This indicates that the temperature increase according to the rising load is similarly proportional.

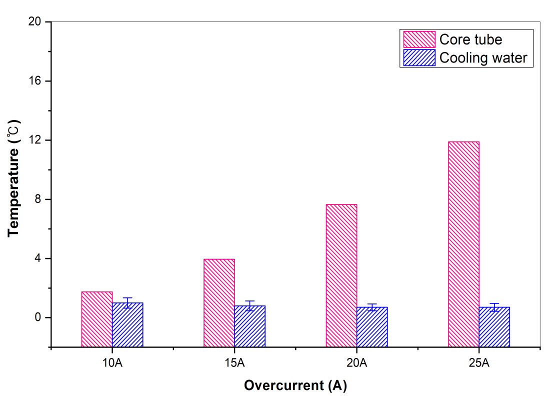
The standard deviation of circulating cooling water for a temperature increase of 15℃ due to overcurrent ranges from 0.27 to 0.35. Also, the inlet-outlet temperature difference was rather uniform, with a variation of around 1℃ under all conditions, indicating that there was minimal difference.

This shows a similar trend to the 25℃ cooling water condition in the previous study (Lee and Kim, 2023).

The condition of supplying cooling water at a flow rate of 13ℓ/min from the constant temperature tank, relative to the current of the designed core, is deemed to be adequately excessive.

Consequently, it is considered highly probable that MCTs will be sufficiently viable as water-cooled electrical cables in the future. It can be concluded that the cooling effect will be higher if the residence time is maximized by trying to reduce the supply flow rate.

Further research on this matter may be conducted to provide a basic dataset that can be utilized in various ways to determine circulating cooling water capacity according to specifications.



[Fig. 8] Comparison of temperature increase rates.

Ⅳ. Conclusions

In this study, we analysed the temperature characteristics of an insulated multi-4-core tube, using the newly developed glass wool as the insulation material, under the condition of supplying cooling water at room temperature (15℃) and applying overcurrent loads in four sections in the range of 10-25A. We aimed to examine the possibility of future use of this tube as an electrical cable for water cooling.

The experiment was conducted with an overcurrent of 10A as the minimum condition. As a result, the core temperature increased by approximately 1.75℃, from 27.80℃ to 29.55℃. It was also found that the inlet-outlet temperature difference of the circulating cooling water was approximately 1.0℃.

At an overcurrent of 25A, the maximum condition of the experiment, the core temperature increased by approximately 11.90℃, from 28.40℃ to 40.30℃. It can be observed that the temperature increase is slightly higher compared to other conditions.

However, the inlet-outlet temperature difference of the cooling water was approximately 0.7℃, which was similar to the minimum condition of 10A.

Therefore, the supply flow rate of 13 ℓ/min for the cooling water was considered an excessive setting value.

The average temperature of the core increased by approximately 10.15℃ when the overcurrent was increased from 10A to 25A. Thus, it can be inferred that the temperature increase of the core due to an increase in load is directly proportional. This could be utilized as basic data for determining the permissible current capacity of the MCTs in the design of future electrical cables.

The inlet-outlet temperature difference of the circulating cooling water at the room temperature of 25℃ remains highly consistent at approximately 0.7– 1.0℃ under all conditions, with a standard deviation ranging from 0.27 to 0.35, indicating a rather uniform level. This is because the flow supplied exceeds the amount of overcurrent, resulting in insufficient heat exchange time. It is anticipated that increasing the residence time of cooling water by optimized flow reduction adjustments throughout future design would result in a higher cooling effect.

Based on this study, the insulated MCTs, which has high versatility as an essential component of ships, may be sufficiently utilized as a water-cooled electrical cable. Therefore, we plan to conduct further research using various condition changes.

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