Heat generation characteristics of the annealed duplex stainless steel thermo-rod for hyperthermia

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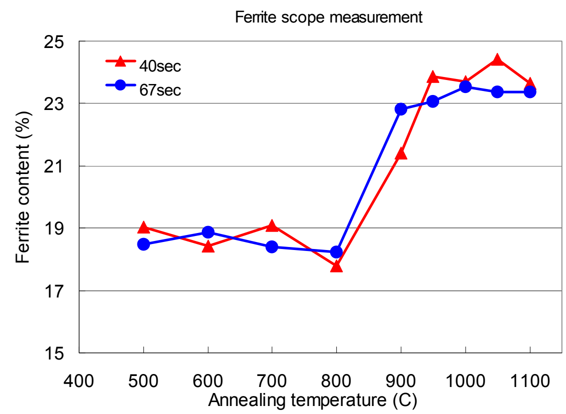
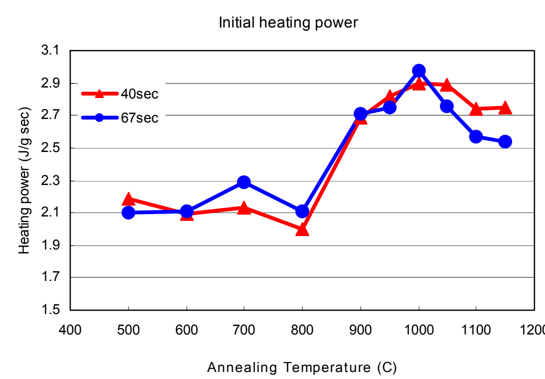
Introduction: Hyperthermia is a one kind of thermal therapy for destroying the heat-sensitive cancer cell by heating between 42□ and 46□. It was reported that several logs of cell kill by hyperthermia at progressively increasing time at temperature above 43□ because of the modification of cytotoxicity by nutrient deficient and hypoxia resulting acidic conditions. Proteins of cancer tissue may irreversibly denature during the hyperthermia and cellular death may occur at these elevated temperatures. A duplex stainless steel(DSS) thermo-rod for hyperthermia can generate therapeutic heat up to its unique temperature inside of the alternating induction magnetic field. There are two most abundant phases in the DSS; magnetic alpha phase (ferrite) and nonmagnetic gamma phase (austenite). The ratio of these two phases is an important factor that can affect the maximum temperature of the thermo-rod which can be controlled by heat-treatment. Also, its exothermic characteristic within an alternating induction magnetic field is closely related to the magnetic field strength, posture, magnetic property of thermo-rod, size and its configuration. In this study, the heat-generation characteristics of the annealed DSS thermo-rod were investigated in order to apply to the interstitial local hyperthermia.

Methods: Thermo-rods were made of the annealed DSS wire Ø1.0mm in diameter (KOS Ltd., Korea) at nine annealing temperatures, i.e. 500, 600, 700, 800, 900, 950, 1000, 1050 and 1100° C. Ratio of the ferrite to austenite was measured with a ferrite scope and calculated from metallographic pictures. Final saturation temperature, initial heating power and characteristic slope of the thermo-rod were analyzed from heating curves. Hardness of the annealed thermo-rod was measured with a Vicker's hardness tester. Chromium and nickel compositions were semi-quantitatively analyzed with an EDX. In order to measure heat generation characteristics of the annealed DSS thermo-rods, calorimetric analysis was carried out using a calorimetric chamber filled with 0.5mL distilled water. The chamber was exposed in an induction heating coil system (7 kW x 20%, 104 kHz, 9 turns, 40cm diameter and 20cm height) and the temperature changing data were acquired using an acquisition device. The characteristic heating power of the thermo-rod at every temperature was calculated from the exothermic heating curve and it was normalized with its weight.

Results: Ferrite ratio of the annealed thermo-rod below 800°C is about 18% and about 24% for higher annealed conditions as shown in the Figure. However the ferrite volume ratios are in the range of 48-57% depending on annealing condition. In the beginning of induction heating, the heating power of thermo-rod shows the highest value, and it decreases linearly as the chamber temperature increases. The initial heating power of the annealed thermo-rods are 2.0 - 3.0 J/g·sec. The slope of heating curve represents an exothermic characteristic and are in the range of 0.028-0.033 J/g·sec·deg. These characteristics may be very helpful for designing clinical hyperthermia cancer treatment conditions. As the annealing temperature increased, the hardness value decreased gradually from Hv 410 to Hv 260 and the nickel composition in ferrite phase increases slightly from 24.1 to 24.6 wt%.





Conclusions: A DSS thermo-rod can generate therapeutic heat for hyperthermia in the induction magnetic field and its heat generation characteristics are able to be controlled by changing annealing temperature conditions.

References:

Kim YK, Kim S, Lee JH "Thermal ablation effects of duplex stainless steel thermo-implants" Materials Science Forum, 2003; 426-432; 3249-3254,

Acknowledgement: This study was supported by a grant of the Ministry of Health & Welfare 2008, Republic of Korea (A085062)