IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Annales de Chimie - Science des Matériaux
Vol. 47, No. 2, April, 2023, pp. 105-110
Journal homepage: http://iieta.org/journals/acsm

# The Effect of Quenching in Different Concentrations of Alumina Nano Fluids on Overall Properties of Al-6061

Sadiq Hassun Abdulazeez Al-Kabi[1], Baydaa Abdul Hassan Khalaf Al-Ghzawi[1], Idrees Hammoody Ahmed[1*], Sabah Mohammed Mlkat Al-Mutoki[2], Haney Al-Kaneyni[1]

[1] Mechanical Department, Al Furat Al Awsat Technical University, Technical Institute of Samawa, Al-Samawah 66001, Iraq
[2] Electrical Department, Al Furat Al Awsat Technical University, Technical Institute of Samawa, Al-Samawah 66001, Iraq

Corresponding Author Email: idrees.ahmed.ism@atu.edu.iq

https://doi.org/10.18280/acsm.470207

**Received:** 2 November 2022
**Accepted:** 14 March 2023

***Keywords:***
*nano fluids, Al-6061, quenching in nano fluids, TEM of quenched Al*

**ABSTRACT**

Different concentrations of nano-alumina solution ranging from (0.1-0.4) were used as hardening solutions for aluminum alloy 6061, where the effect of the change in concentrations on the microstructure of the surface of the samples was studied, as well as its effect on the mechanical properties of the same samples. The interaction of Nano-particles from the solution with the surface of the sample was detected by tunneling electronic microscope (TEM), this good interaction led to a noticeable increase in its mechanical properties and the highest increase was when the concentration of the Nano solution was 0.3%.

## 1. INTRODUCTION

Quenching is one of the most important thermal treatments used to improve the properties of metals in general. During the past two decades, the focus has been on quenching in different nano-solutions, such as carbon Nano-tubes, alumina Nano-particles, and other Nano-scale solutions [1]. Nano fluid has become popular with the advancement in nanotechnology. Nano fluid has comparatively better stability than the micro fluid because here much smaller-sized particles (nanometer size) are suspended in the base fluid. It has improved thermophysical properties and convective heat transfer coefficient than the base fluid alone. That is why researchers have implemented this novel heat transfer fluid in versatile fields. These are solar collectors, solar thermal energy storage, electronics cooling, cooling and heating, heat pipes, automobile radiator, refrigeration system, natural convection, quenching, and many other applications. These varied applications indicate that in imminent future nano fluid will play a major role in these fields. Though all these trials are at present at academic research level, however, with the advancement in difference in results when tempering in ordinary water and tempering in nano-solutions [2-4].

## 2. EXPERIMENTAL PART

### 2.1 Materials

The metal samples with dimensions (100*50*5) mm, are made of an aluminum alloy (6061)-T651 which chemical composition and mechanical properties is as shown in Table 1 and Figure 1.

Nanotechnology surface science, colloidal chemistry, and so forth, this nanofluid will definitely play a major role in heat. For example, the authors [1] studied the quenching properties of metal base rod lets and spherical shapes were thou in toughly studied after immersing in water and water-based Nano-fluids with alumina nano-particles of 0.1% by volume fraction. The tests were occurred at both high saturated and sub cooled environments under atmospheric pressure [5-9]. The results showed that while the initial super cooling behavior in Nano-fluids is identical to that in pure water, yet the minimum heat flux point temperature and super cooling front speed are a in subsequent quenching repetitions due to Nano-particle deposition. The effect of Nano powders on the super cooling process was dissection according to the contact between the Nano particles and the alloy surface, it appears that the liquid-solid interaction during such short-lived contacts is more vigorous when a Nano-powder layer with enhanced surface wettability and harshness is found, which leads to the premature disruption of film boiling and quenching super cooling [10-19].Through this research paper, we hope to study the effect of the difference in the concentration of nano-alumina solution on the morphology and mechanical properties of Al-6061.

**Table 1.** XRF analysis and mechanical properties aluminum alloy (6061)–T651

| Stand. Indent | Cu | Mg | Si | Fe | Mn |
|---|---|---|---|---|---|
| 6061 | 3.0 | 3.0 | 8.7 | 1.2 | 0.5 |
| Mech. Prop. | Hardness (HRC) (Kgf 150) 37 | | | | |
| **Stand. Indent** | **Ni** | **Zn** | **Pb** | **Ti** | **Al** |
| 6061 | 0.39 | 3.0 | 0.28 | 0.2 | Equ. |
| Mech. Prop. | Yield Stress ($N/mm^2$) 200 | | | | |

**Figure 1.** Picture for the quenched samples

### 2.2 Preparation of alumina nano-fluid

The two-step preparation process is used by Eastman et al. [17]. was used to produce alumina nano-fluids in which includes mixing base fluid. A 99.99% nano alumina powder supplied by (MERCK, Germany) with (0.1, 0.2, 0.3, and 0.4) weight percent and distilled water were mixed in an ultrasonic vibrator, to stir nano-powders with host fluids 500 rpm vibration for 3 hrs. was applied to reduce particle agglomeration and ensure a homogeneous distribution as shown in Figure 2.

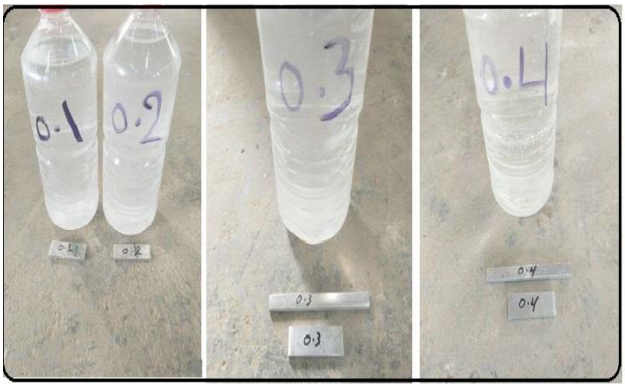



**Figure 2.** Illustrated quenching nano alumina fluid starting from (0.1 up to 0.4) concentration with 6061 T6 Aluminum alloy before quenching process

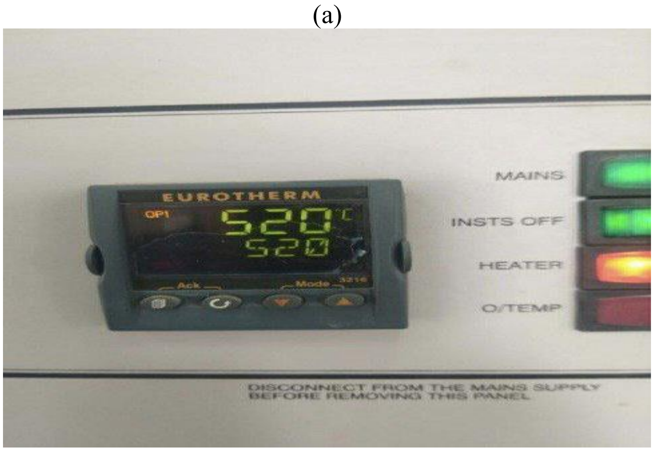
### 2.3 Quenching process

Quenching process includes two steps, the first is heating the aluminum samples up to 520℃, and this was occurred using an electrical evacuated furnace type (Bogie Hearth Furnaces) as shown in Figures 3(a) and (b). Then the hot aluminum specimens were suddenly cooling in the prepared nano-alumina solutions as shown in Figure 4. After all the samples has been treated in the prepared different concentrations of alumina nano fluid the mechanical tests were performed.

### 2.4 Mechanical tests

The tensile strength was tested by using a (Testometric England M500-100CT Device) connected with computer, the sample in the fixture of tensile test device as shown in Figures 5(a) and (b). The hardness number was tested by using (India Rockwell device) as shown in Figure 6. The results obtained from the above mechanical testing are shown in the Table 2. The change in the surface structure of the samples was studied using tunneling electronic microscope TEM as shown in Figure 7.

(a)




(b)

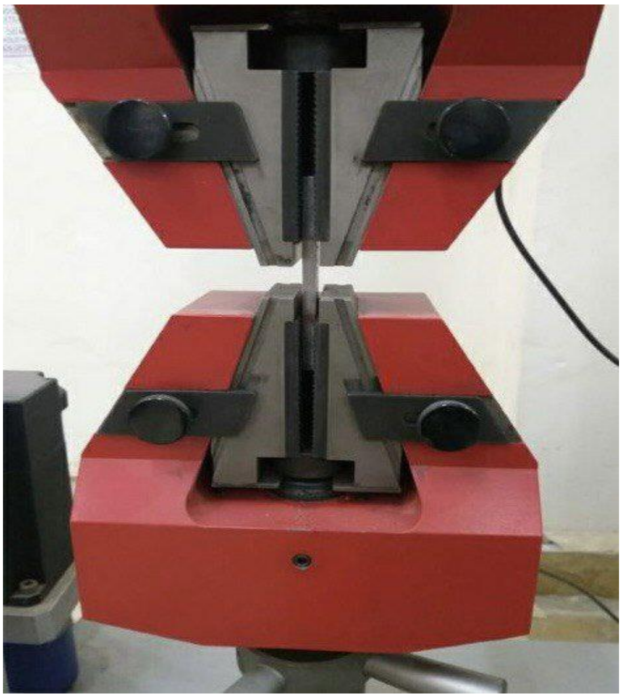
**Figure 3.** Illustrated the pictures of (a) the electrical furnace used with (b) the indicator of heating temperature

**Figure 4.** Pictures for the quenched samples

**Table 2.** Mechanical properties for the quenched samples

| Sample No. | Hardness (HRC) (Kgf 150) | Yield Stress ($N/mm^2$) |
|---|---|---|
| 0.0 | 49.33 | 271.6 |
| 0.1 | 78.33 | 318.8 |
| 0.2 | 83.1 | 364.8 |
| 0.3 | 89 | 504.667 |
| 0.4 | 79.83 | 358.4 |


(a)



(b)

**Figure 5.** Illustrated the pictures of (a) tensile test device, (b) sample in the fixture test device

**Figure 6.** Illustrated the picture of hardness test device

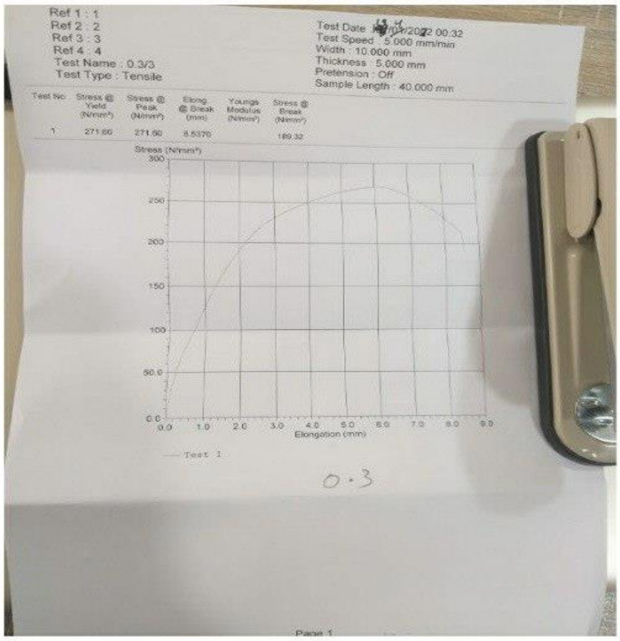



**Figure 7.** Illustrated the plot of the tensile test

## 3. RESULTS AND DISCUSSION

Cooling in nano-solutions affects the overall properties of metal alloys more than ordinary solutions according to the opinion of many researchers. This effect is due to two main axes, the first is the infinitesimal size of the nano-plankton scattered in the solution, which enables it to enter the smallest voids in the microstructure of the alloy subject to the quenching process and occupy these voids, which eliminates or reduces the porosity and interfacial voids of the alloy. Thus, the overall mechanical properties are expected her to rise. As for the second axis, it is the axis of the chemical reaction, as the conditions surrounding the solidification process, including the large difference between temperatures, create what helps the chemical bonding between the metal compounds in the alloy and the nano-phase present in the solution, which leads to the formation of new compounds with high mechanical properties. This may be seen in Figure 8 which state the difference between the non-treated Al-6061, and the difference in morphology resulted from the difference in nano alumina solution. The distribution, and non-agglomerated nano alumina phase is so clear.

Table 2 declares the difference between the super cooling in distill water specimen (0.0) and the super cooling with alumina nano fluids solutions it is clear even with the smallest concentration (0.1) there was a remarkable enhancement with hardness and yield stress this increment is directly proportion with concentration of alumina nano fluids. From the same table it is shown that the critical value of concentration was (0.3) which indicate the maximum increment in both hardness with (89kgf) and yield stress (504.667N/mm$^2$), then it was decrease at a concentration 0f (0.4). So, it is true if we state that the best alumina nano fluid concentrate for getting the maximum properties is (0.3%) as shown in Figures 9-13.

From the above Figure 9, we notice that the maximum tensile strength value is (271.6N/mm$^2$) for specimen quenched in distill water, while the maximum tensile strength value for specimen quenched in 0.3 Nano solution is (504.667N/mm$^2$), as well as the value of hardness Rockwell number improved from (49.33kgf) to (89kgf) Table 2, this clear that the affected of Nano solution content in quenching process.

Several researchers suggested that oxidation leads to deterioration of aluminum surface, but a mixed effect of oxidation and nanoparticles deposition during the quenching process, altered the surface roughness of the surface and improved mechanical properties. Hence, it was possible that the effect of surface morphology changes during quenching influenced the overall mechanical properties which enhanced in the rapid cooling in alumina nano fluids [20].

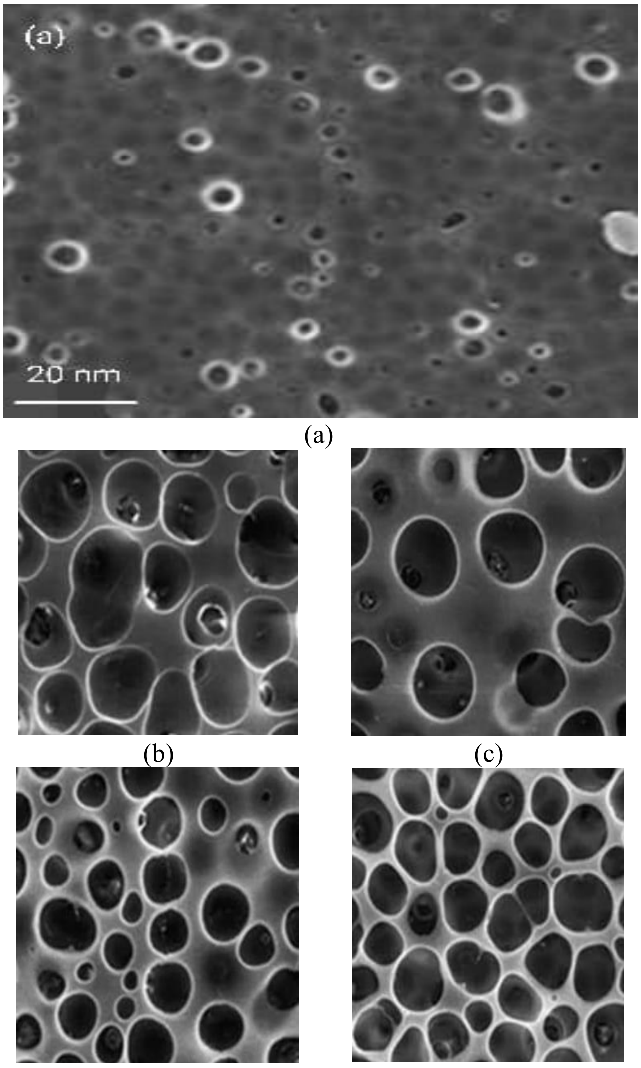


**Figure 8.** TEM of (a) quenching in distill water only, (b) quenching in (0.1) Nano alumina solution, (c) quenching in (0.2) Nano alumina solution, (d) quenching in (0.3) Nano alumina solution and (e) quenching in (0.4) Nano alumina solution

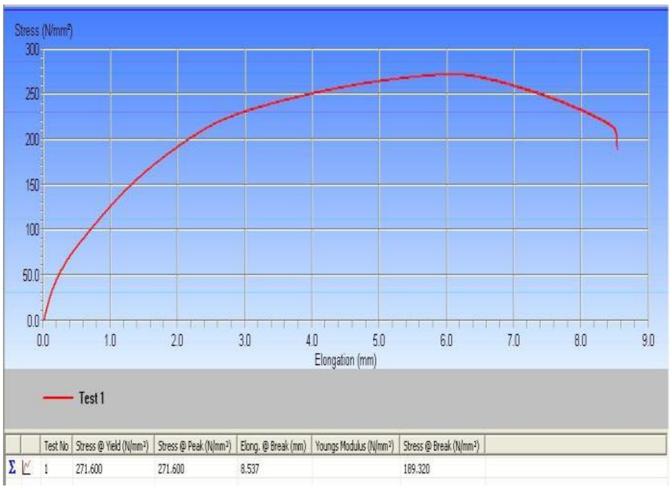


**Figure 9.** Tensile test diagram for specimen quenched in distill water

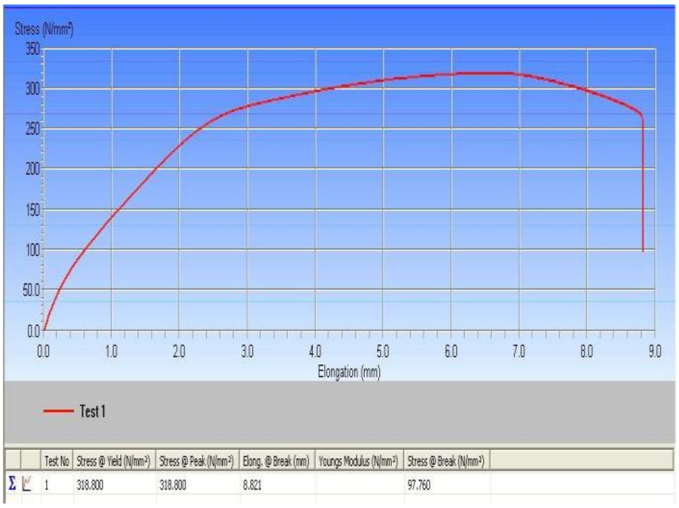


**Figure 10.** Tensile test diagram for specimen after quenched in (0.1) nano solution the maximum tensile strength value is (318.8N/mm$^2$), as well as the value of hardness Rockwell number is (78.33kgf)

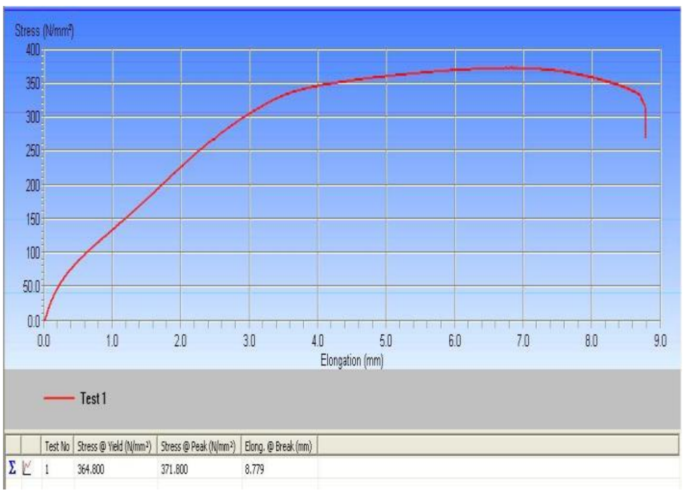


**Figure 11.** Tensile test diagram for specimen after quenched in (0.2) nano solution the maximum tensile strength value is (364.8N/mm$^2$), as well as the value of hardness Rockwell number is (83.1kgf)

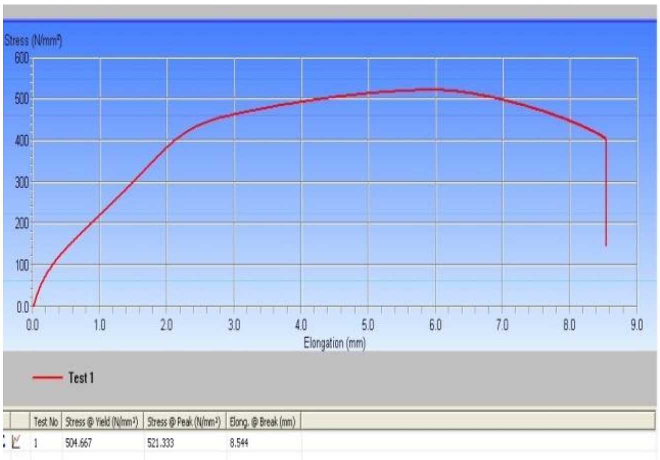



**Figure 12.** Tensile test diagram for specimen after quenched in (0.3) nano solution the maximum tensile strength value is (504.667N/mm$^2$), as well as the value of hardness Rockwell number is (89kgf)

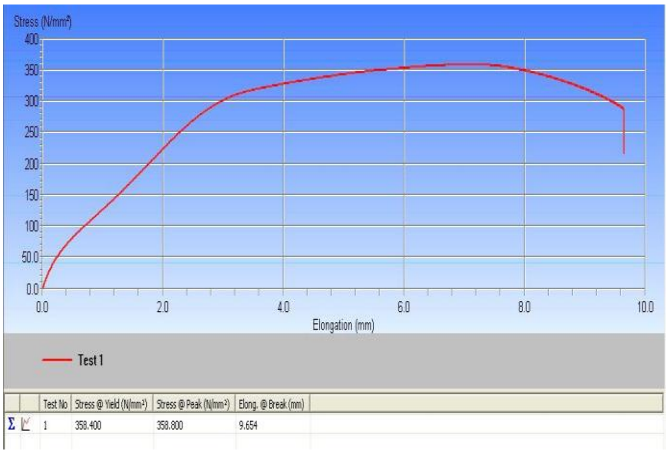



**Figure 13.** Tensile test diagram for specimen after quenched in (0.4) nano solution the maximum tensile strength value is (358.4N/mm$^2$), as well as the value of hardness Rockwell number is (79.83kgf)

## 4. CONCLUSION

From the above, we may conclude that the rising of mechanical properties like hardness and strength after quenching in alumina nano fluids is due to the high interaction between the nano particles spread within the nano fluid which create both mechanical interlock as it is obvious from TEM images, and a chemical interaction to form a new chemical composition on the surface of the alloy, we may also conclude that the critical concentration of alumina nano fluid that gives the ultimate mechanical properties is 0.3% among the other concentrations.

## REFERENCES

[1] Kim, H., Buongiorno, J., Hu, L.W., Mc-Krell, T. (2010). Nanoparticle deposition effects on the minimum heat flux point and quench front speed during quenching in water-based alumina nanofluids. International Journal of Heat and Mass Transfer, 53(7-8): 1542-1553. https://doi.org/10.1016/j.ijheatmasstransfer.2009.11.029

[2] Cui, X., Wan, M., Ma, B., Wu, X., Han, J. (2019). Quenching by immersion considering boiling heat transfer. International Journal of Thermal Sciences, 139: 303-311. https://doi.org/10.1016/j.ijthermalsci.2019.01.039

[3] Dey, D., Sahu, D.S. (2021). A review on the application of the nanofluids. Heat Transfer, 50(2): 1113-1155. https://doi.org/10.1002/htj.21920

[4] Shkolin, A.V., Fomkin, A.A., Men'shchikov, I.E., Yakovlev, V.Y. (2018). Supramolecular nanoporous carbon materials based on the arrays of carbon nanotubes, ordered by cyclic hydrocarbons for methane and hydrogen storage. Materials Today: Proceedings, 5(12): 25911-25915. https://doi.org/10.1016/j.matpr.2018.08.002

[5] Wang, J., Fei, X., Liu, H., Zhang, L. (2022). Cooling time and CHF enhancement of reactor vessel cooling process by flame sprayed porous coating in different orientations. Nuclear Engineering and Design, 390: 111706. https://doi.org/10.1016/j.nucengdes.2022.111706

[6] Li, X., Zhu, D., Wang, X. (2007). Evaluation on dispersion behavior of the aqueous copper nano-suspensions. Journal of colloid and interface science, 310(2): 456-463. https://doi.org/10.1016/j.jcis.2007.02.067

[7] Chandrasekar, M., Suresh, S., Bose, A.C. (2010). Experimental investigations and theoretical determination of thermal conductivity and viscosity of Al2O3/water nanofluid. Experimental Thermal and Fluid Science, 34(2): 210-216. https://doi.org/10.1016/j.expthermflusci.2009.10.022

[8] Hwang, Y., Lee, J.K., Lee, J.K., Jeong, Y.M., Cheong, S. I., Ahn, Y.C., Kim, S.H. (2008). Production and dispersion stability of nanoparticles in nanofluids. Powder Technology, 186(2): 145-153. https://doi.org/10.1016/j.powtec.2007.11.020

[9] Lee, C.Y., Chun, T.H., In, W.K. (2014). Effect of change in surface condition induced by oxidation on transient pool boiling heat transfer of vertical stainless steel and copper rodlets. International Journal of Heat and Mass Transfer, 79: 397-407. https://doi.org/10.1016/j.ijheatmasstransfer.2014.08.030

[10] Dong, K., Ding, S., Chen, D., Wu, D., Deng, J., Liu, H., Liu, H., Ma, Z. (2022). An experimental study of quenching propagation along narrow rectangular channels. International Communications in Heat and Mass Transfer, 133: 105969. https://doi.org/10.1016/j.icheatmasstransfer.2022.105969

[11] Sakashita, H., Ono, A., Nakabayashi, Y. (2010). Measurements of critical heat flux and liquid-vapor structure near the heating surface in pool boiling of 2-propanol/water mixtures. International Journal of Heat and Mass Transfer, 53(7-8): 1554-1562. https://doi.org/10.1016/j.ijheatmasstransfer.2009.11.028

[12] Wang, J., Fei, X., Liu, H., Zhang, L. (2022). Cooling time and CHF enhancement of reactor vessel cooling process by flame sprayed porous coating in different orientations. Nuclear Engineering and Design, 390: 111706. https://doi.org/10.1016/j.nucengdes.2022.111706

[13] Kim, H., Buongiorno, J., Hu, L.W., McKrell, T. (2010). Nanoparticle deposition effects on the minimum heat flux point and quench front speed during quenching in water-based alumina nanofluids. International Journal of Heat and Mass Transfer, 53(7-8): 1542-1553.

https://doi.org/10.1016/j.ijheatmasstransfer.2009.11.029

[14] Suriani, A.B., Norhafizah, J., Mohamed, A., Mamat, M. H., Malek, M.F., Ahmad, M.K. (2016). Scaled-up prototype of carbon nanotube production system utilizing waste cooking palm oil precursor and its nanocomposite application as supercapacitor electrodes. Journal of Materials Science: Materials in Electronics, 27: 11599-11605. https://doi.org/10.1007/s10854-016-5291-x

[15] Razavi, R.S., Gordani, G.R. (2011). Laser surface treatments of aluminum alloys. Recent Trends in Processing and Degradation of Aluminium Alloys, 115-154. https://doi.org/10.5772/18451

[16] Musfirah, A.H., Jaharah, A.G. (2012). Magnesium and aluminum alloys in automotive industry. Journal of Applied Sciences Research, 8(9): 4865-4875.

[17] Eastman J.A., Choi S.U.S., Li S., Yu W., Thompson L.J., 2001. Anomalously increased effective thermal conductivities of ethylene glycol-based nanofl uids containing copper nanoparticles. Appl. Phys. Lett., 78: 718-720. https://doi.org/10.1063/1.1341218

[18] Lowe, T. C. (2006). Outlook for manufacturing materials by severe plastic deformation. In Materials Science Forum, vol. 503, pp. 355-362. Trans Tech Publications Ltd.

[19] Ismail, H., SULAIMAN, M.Z., Okawa, T. (2022). Heat transfer characteristics of metallic body during quenching in saturated nanofluids. International Journal of Automotive and Mechanical Engineering, 19(1): 9403-9411. https://doi.org/10.15282/ijame.19.1.2022.04.0723

[20] Sharma, A.K., Modak, M., Sahu, S.K. (2016). Experimental investigation of rewetting during quenching of hot surface by round jet impingement using $Al_2O_3$–Water nanofluids. In International Conference on Nuclear Engineering. American Society of Mechanical Engineers, 50039: V003T09A056. https://doi.org/10.1115/ICONE24-60732