

Investigation of New Material for Deterging Heat Exchanger Tube

Mohamed Khaled Mohamed Mohamed Hasanin

Physics and Mathematics Department, Higher Institute of Engineering, El Sherouk Academy, Cairo, Egypt

Email address:

mkhalidmmh@gmail.com

To cite this article:

Mohamed Khaled Mohamed Mohamed Hasanin. Investigation of New Material for Deterging Heat Exchanger Tube. *Advances in Materials*. Vol. 12, No. 2, 2023, pp. 17-24. doi: 10.11648/j.am.20231202.11

Received: February 16, 2023; **Accepted:** March 10, 2023; **Published:** May 29, 2023

Abstract: This work represents new material can be used in cleaning process of heat exchanger tubes. Rubber projectiles are back bone of on line cleaning mechanism but it has poor mechanical and thermal features. Three materials have different properties with micro scale powder solid phase (aluminum, aluminum oxide and copper) had been added to (LSR) with different volume ratios (2%, 5%, 10%, 15%). specimens had been prepared with certain method and under specific conditions. Compression test was applied to identify stiffness factor of these new composite materials. Wear test was applied to finite the wear rare coefficient for these materials. Un certainty statistics was applied for measurements results so It's founded that with increasing volume ratio each of stiffness factor and wear rate coefficient increase linearity up to (15%) for all specimens. copper filler give best for stiffness that stiffness factor reaches about (30 (N/(mm/mm))) at volume ratio 15%) but poorest wear resistance with wear rate coefficient (9×10^{-6}) Mpa^{-1} inversely aluminum filler gives best results in wear resistance with wear rate coefficient (6×10^{-6}) Mpa^{-1} but weakest in stiffness test with stiffness factor (28 N/(mm/mm) at volume ratio 15%). Aluminum oxide was the best choice for new projectile material as it combines between good stiffness and wear resistance.

Keywords: Stiffness Factor, Wear Rate Coefficient, Silicone Rubber, Projectile Ball

1. Introduction

Cleaning heat exchanger represents the most important step through its operation cycle. on line cleaning mechanism is more economic than other cleaning systems and save time as heat exchanger still working during cleaning process. Injection projectiles considered one of most effective method for mitigation fouling from heat exchanger tubes. A lot of researches have been discussed mechanism, type of fouling and injection cycle but few researchers studied types of this projectiles ball and all of these researches applied available balls that valid on market but no one discussed the material of this projectiles. The balls available in market may be rubber and sponge types from this information silicone rubber with additives may be suitable material for this ball. So literature will discuss silicone rubber and its additives also will discuss cleaning process of heat exchangers by projectiles ball. Tensile strength of (LSR) upgraded by increasing amount of surface modified Nano silica particles that have been added to (LSR) matrix [1]. It's founded that for different polymer material composition sliding distance;

speed and load have strong impact on specific wear rate [2]. Pneumatic projectiles technique that depends on pressure force contact between pipe and projectiles is extra ordinary for achieving high level of cleanness for different traditional applications with various materials and sponge type with and without surface coating projectiles is compatible for all tube's material [3]. Projectiles can remove fouling from tubes of heat exchanger until deposits reach it's asymptotic region not only projectile material type but also injection rate won't play rule in cleaning process [4]. studying chemistry of adhesion between silicone rubber and metals especially aluminum has founded that silanes achieve good adhesion by cross condensing hydroxyl group of metal surface [5]. surface texture and hardness of projectile ball have the main rule on its cleaning performance. Different material and geometry balls had been studied for different injection rate and for certain fouling and it's founded that for best performance projectile must be high stiffness and roughness also must be flexible in motion through tube [6]. Stiffness and contact area of projectiles represent most effective features for cleaning heat exchanger's tubes also harder projectiles are preferable

than softer one also size is very important for selection projectiles different types of projectiles have been tested and optimum one has %1 deformation with 0.6N [7]. Shear force is most important feature that join between contact area and shear stress on projectiles balls also degradation of sponge balls depend on its size larger size has high degradation level but more effective cleaning process than smaller size with no noticeable degradation but lower cleaning efficiency [8]. Adding carbon nano tube filler enhance mechanical and thermal properties of Aluminum oxide liquid silicone rubber composite also micro powder (Al_2O_3) very compatible to liquid silicone rubber [9]. It's founded that adding filler to (LSR) strengthen not only its poor mechanical properties but also electrical properties and strain sensitivity also these properties increase by increasing content percent of filler [10]. Improvement of cleaning system reduce losses in rubber balls good design for heat exchanger tube reduce wear of ball material and it's important to choose ball with suitable size to control the thermal expansion of its material [11]. applying wear test to composite materials show that volume abrasion increase linearity with sliding distance also higher hardness composite material cause higher volume abrasion [12]. Different percent of wo_3 nano particles had been added to LSR and its found that highest density specimens give best properties in against gamma rays [13]. The highest density holding silicon In automatic cleaning heat exchanger projectile balls size must adjusted according tube diameter also it's founded that wear phase of balls is very good indicator on cleaning effect and efficiency [14]. The objective of this work is investigation the stiffness and wear resistance of rubber projectile that can be used for cleaning heat exchanger. (LSR) is used as base matrix and three metal powder are be used as fillers (copper, aluminum and aluminum oxide) as these materials not usual using as filler for polymer also they have different densities so will give different mechanical properties [15]. Different volume percent for fillers applied then stiffness and wear resistance had been measured.

2. Method

This work will depend on experimental study for composite long life projectiles material use for (online) cleaning condenser [7]. Liquid silicone rubber (LSR) is the base material and other metals filler like copper and aluminum) also ceramics like aluminum oxide (Al_2O_3) will be added to (LSR). These filler had been chosen due to enhancement thermal and mechanical properties for only silicone rubber projectiles. Cleaning process depends on a lot of factors but stiffness and wear resistance still the most important properties for projectile materials so this study depends on finding best stiffness and wear resistance material.

2.1. Specimens' Preparation

Sphere Shape with diameter 36 mm has been chosen for this experiment as it lies in diameter range of commercial projectile (14-44 mm) [12] sphere specimen volume= (24.4

ml) used for stiffness measurement. Cylindrical with volume (10 ml) used for wear resistance measurements specimens. As silicone rubber in liquid phase white color and has stable temperature resistance reach to 200°C has been used was 25 gram of hardener blue color to 1000 gram of silicone rubber so for 40 grams need about 1 gram of hardener and has specific gravity (1.2) also these different fillers will be powder particles with equal micro scale particles about (50 μ m) and they have specific density for copper (6.8), (2.7) for aluminum and (3.5) for aluminum oxide then after certain preparations we obtained specimens as shown in figure 1.



Figure 1. Illustrate specimens prepared for wear and compression test.

Different percentages per volume ($VR = V_{\text{filler}}/V_{\text{total}}$) from fillers have been added to silicone (2%, 5%, 10%, and 15%) from total volume of specimens. this percentage chosen according that a lot of mechanical and other properties give good measurable behavior through (0-30%) percent [14]. High accuracy scale has been used to finite amount of mass for each element in the total final volume as

$$M_i = \rho_i \times V_i \quad (1)$$

$$V_t = \sum V_i \quad (2)$$

(LSR) was poured and the metal powder afterwards and mixed thoroughly with each other and after an average of 10 minutes of stirring it was put inside the vacuum machine in order to remove the bubbles because they cause defects and deteriorate mechanical properties. The mixture was observed inside the vacuum pump until most of the bubbles have disappeared, and then removed. we chose not to add the hardener before adding it to the pump because it wouldn't

give us sufficient time for vacuuming and would harden before we could pour it. So after removal of the mix from the pump we added the hardener and after an average of two minutes of stirring we poured the mix into the mold for stiffness and wear test. The mixture required 15 hours to sit in the mold to completely solidify and then we can remove sample for testing. It's very important to sure that same ambient condition it was (25°C, 40% RH, 1atm) in each experiment to control the effect of environment on results and this reduces uncertainty in measurements.

2.2. Measurements Methodology

Measurements will divide into two branches first compression for measuring stiffness factor for spherical specimen and then wear test for cylindrical specimen for measuring wear coefficient rate.

2.2.1. Compression Test

Spherical specimens were exerted from mold the test must occur to compress ball to its half of diameter (from D to D/2) this chosen according standard criteria [7]. Then we applied this test on universal compression machine of polymer in poly lab at faculty of engineering (AIN SHAMS university) in Figure 2 we choose flat plate as sample holder we choose Pre load = 0.5 N, Speed of loading = (100 mm/min) An important issue that occurred during test that sample must be in the middle of die some non effected layer of lubricant added on both surfaces the tool wouldn't stick on the surface. The main obtained was relation between load (N) and extension (mm). Relation between load and extension had been measured for many times for several specimens from same composition to overcome random error and reduce uncertainty in measurements then some statistics analysis value used for analysis results.

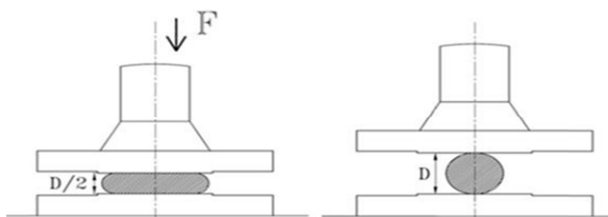


Figure 2. Illustrate of universal compression machine.

A lot of data obtained from each specimen needed to certain comparative value it was stiffness factor [8].

Stiffness factor (α) = (max load reached/ max strain reached) (3)

Then relation between stiffness factor and volume percent for each material plotted and then curve fitting and regression data analysis applied to obtain linear best fit analysis and sure validation of fitted curve.

2.2.2. Wear Test

There are some problem face polymer specimens to hold on the disk friction wear machine due to high friction or disability to add any lubricant through test. so its decided to

use the polishing machine in [AIN SHAMS] lab as a wear machine it has aluminum disk which was as close as we could get mechanically to the copper walls of heat exchanger pipes. It also had a drainage system which supplied it water and recycled the used water which was very useful to apply wear test.

By using optical manometer we founded that it has two set of speed 100 rpm and 200 (rpm). The result of surface roughness of the disk which are measured by the SRT are RA=0.52 & RZ= 7.14. The hardness of the disk when measured by Rockwell hardness tester was = 62 HRB which equates to (110) Brinell to confirm the hardness portable hardness device has been used. The specimen must but on the same contact area to give accurate comparative results.

To apply pressure load on specimen it will hold the specimen on a cylindrical specific plastic holder the load will change manually. The load will apply on specimen is 2kg and 3kg so it achieve about (20N, 30 N) pressure force. For wear test two loads applied on specimen and distance measured from (velocity of disk, time, and diameter measured from center of disk to center of specimen as shown in Figure 3.

Distance (d) measured from relation

$$d = (0.052 * D * N * t) \quad (4)$$

As: - D (rotating disc diameter (m)), (N rotational speed of disc (rpm)), (t time(s))

Different time will give us different distance but a uniform distance had been taken (1000 m) for all specimens to make compasion between them easier. Mass after and before each measuring trial and we obtained relation between distance and accumulation of weight losses.

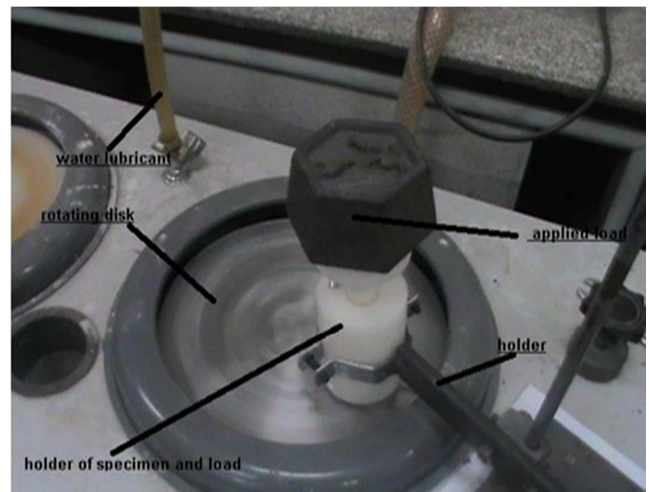


Figure 3. Illustrate test rig used for wear test.

It's important for comparing between different specimens important comparative value (wear rate coefficient K_a (Mpa⁻¹).

$$\text{Wear rate (W)} = ((\text{volume of material removed}) / ((d) \text{ sliding distance})) \quad (5)$$

$$\text{Wear rate constant } K_a = ((W/FN)) \quad (6)$$

Where (FN) is normal force on contact sliding area in this study it will be (20 and 30 N). When wear rate (W) wanted to be calculated we will take the max distance traveled and max weight losses then by multiplying it by density of specimen then obtain volume removed When divide this volume on distance wear rate could be obtained this will repeat for all specimens. Like compression test experiments had applied for a lot of times for a lot of same concentration specimen and same environment condition in each time.

2.3. Uncertainty

It important to say that in this experimental work uncertainty applied included certain track.

First was design stage uncertainty in this step for any device used in measurement.

$$U_0 = (1/2) \text{ resolution} \quad (7)$$

Then static characteristic for any device like linearity, hysteresis, zero drift, and sensitivity had known from device data sheet and then applied on any measured data (U) at this step design stage uncertainty could be calculated Ud.

$$U_d = \sqrt{(U_0)^2 + (U^2)} \quad (8)$$

Second was error propagation calculation and this had been applied for any relation between more than one

measured quantity.

$$R = R(X, Y \dots \text{etc}) \quad (9)$$

$$UR = \sqrt{([\partial R / \partial x] ux)^2 + ([\partial R / \partial y] uy)^2 + \dots} \quad (10)$$

After applying uncertainty on measurement data, relation between VR and stiffness factor applied also VR and wear rate constant plotted to discuss best material a best concentration of fillers.

3. Results and Discussion

3.1. Compression Test

Compression test had applied for copper, Aluminum and Aluminum oxide then data plotted for each filler material as shown in Figure 4 also regression analysis applied for fillers. It's founded that linear fitting was the best for all fillers in these VR and this also for increasing VR stiffness factor increase it illustrated in Figure 7 and this mean that material can withstand large amount of load to deform it and this will be required for removing fouling from tubes. Increasing VR leads to strongest chemical bond between silicone rubber and filler.

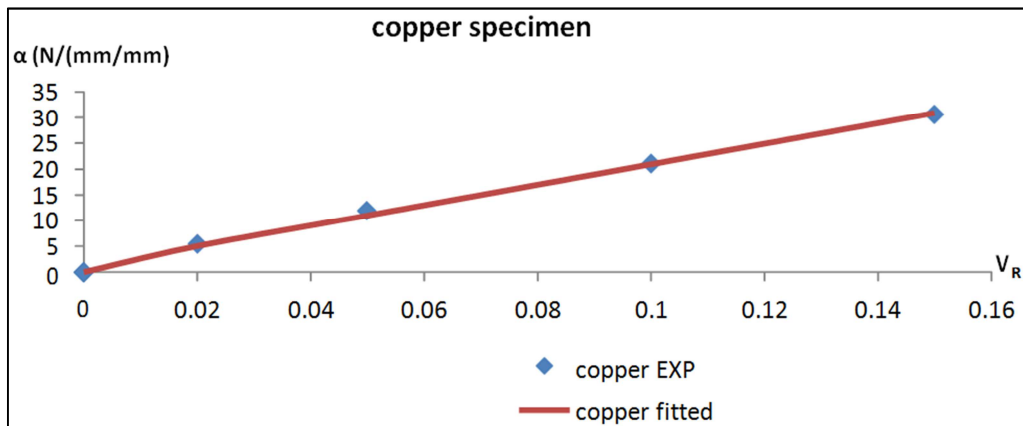


Figure 4. Copper specimen stiffness factor.

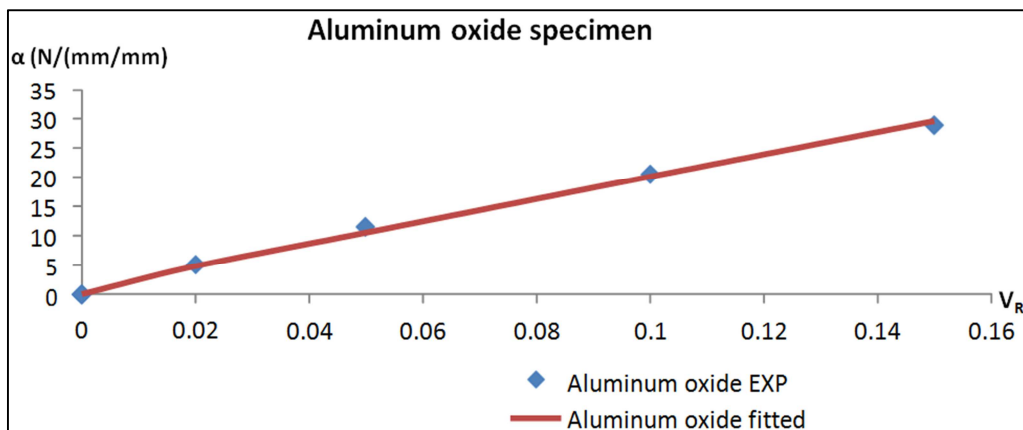


Figure 5. Aluminum oxide specimen stiffness factor.

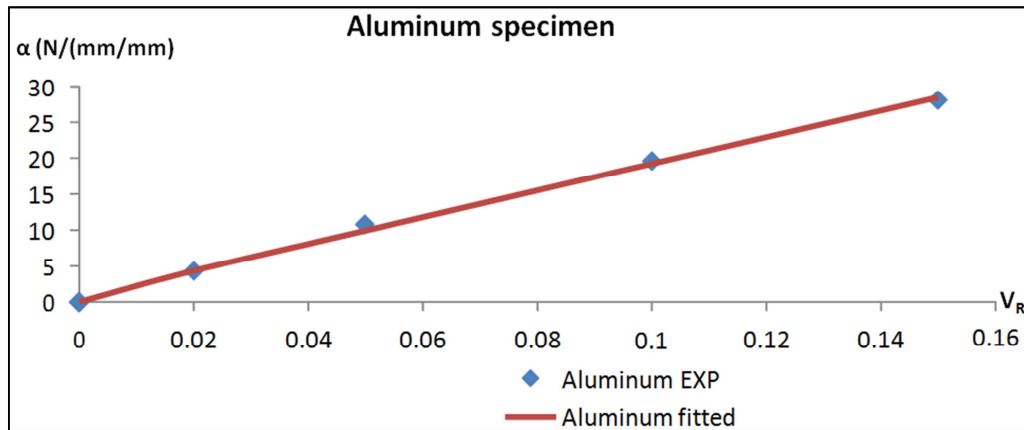


Figure 6. Aluminum specimen stiffness factor.

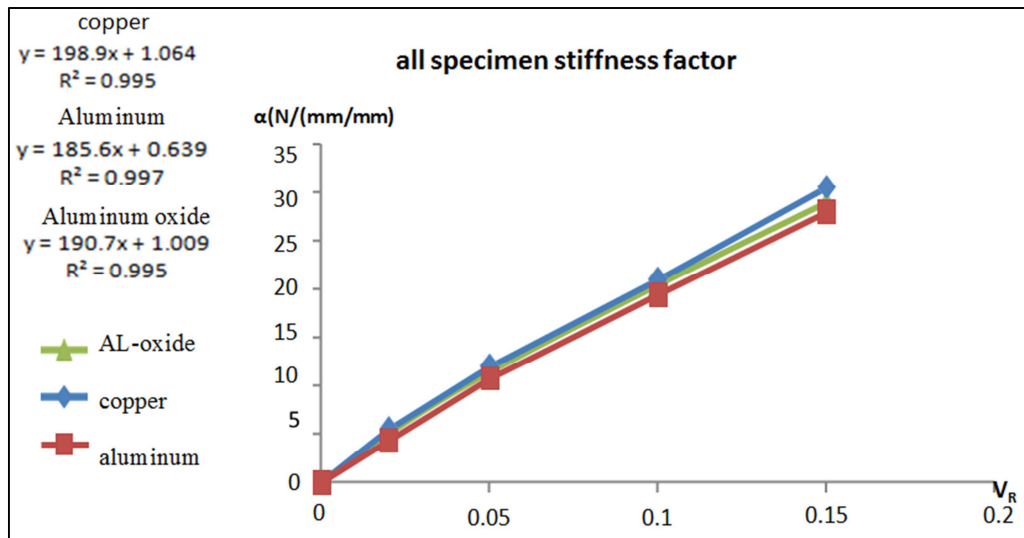


Figure 7. Illustrate all specimen stiffness factors.

Also in Figure 7 all fitted equation plotted on graph to illustrate difference between them. As increase density of filler increase young modulus [14] so this result seem logically according experimental data. There are different specimens but

fitted curve linear so trial to make optimization for VR will give the same value if objective function is max (stiffness factor). Results of measurements putted on Table 1 to show the actual and fitted data for all specimens.

Table 1. Illustrate all specimen stiffness factor.

All specimens of tested materials (stiffness test)							
VR		copper		aluminum		aluminum oxide	
		EXP	Fitted	EXP	Fitted	EXP	Fitted
0		0	0	0	0	0	0
0.02	stiffness factor (α) (N/(mm/mm))	5.5	5.04	4.3	4.35	5.1	4.82
0.05		12	11.01	10.8	9.92	11.5	10.54
0.10		21	20.95	19.5	19.2	20.5	20.08
0.15		30.5	30.9	28	28.48	29	29.6

It's noticeable from Table 1 that increasing VR will increase stiffness factor for all filler materials also copper specimen give largest value of stiffness factor at (VR =15%). And aluminum oxide gives lowest one at same percent. Fitted curve illustrates that relation between VR and stiffness factor increase linearity through (0- 15%).

3.2. Wear Test

By applying wear test on all specimens as demonstrated previous it's founded that for all specimens by increasing VR and applied load on specimen wear rate coefficient (Ka) increase this result seems logically as volume removed from specimen increase. As shown in Table 2. Figure 8 illustrates different specimen under wear test.

Table 2. Illustrate wear test for all specimens.

All specimens of tested materials (wear test)							
VR		copper		aluminum		aluminum oxide	
		2kg (20N)	3kg (30N)	2kg (20N)	3kg (30N)	2kg (20N)	3kg (30N)
0		0	0	0	0	0	0
0.02	$K_a \text{ (Mpa}^{-1}) * 10^{-6}$	0.78	1.84	0.28	0.39	0.49	0.92
0.05		1.77	4.11	1.15	1.29	1.29	2.3
0.10		2.98	6.94	2.47	2.65	2.48	4.29
0.15		3.86	8.99	3.67	3.87	3.5	5.99

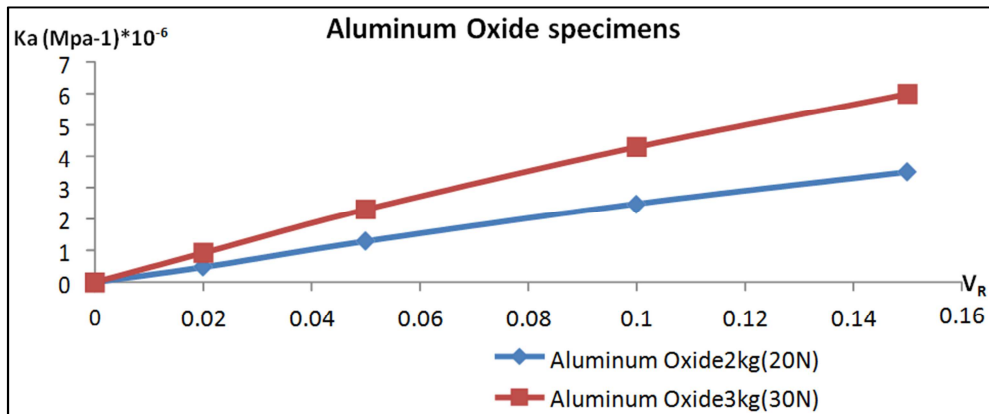


Figure 8. Illustrate Aluminum oxide at different loads.

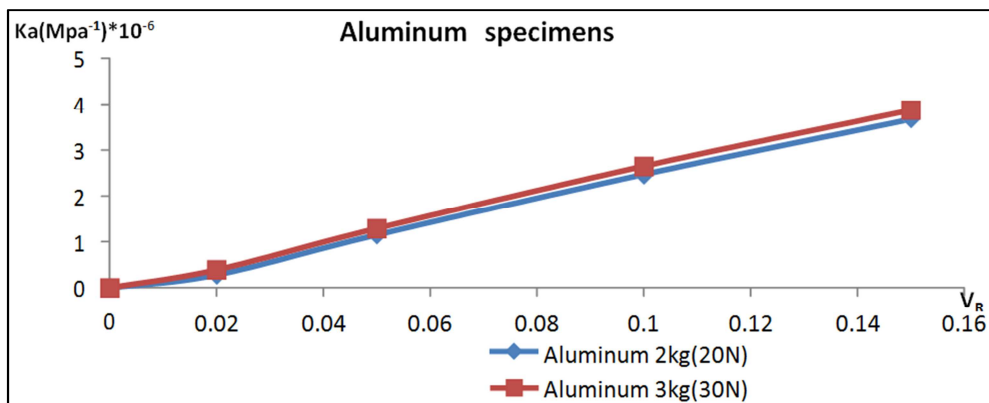


Figure 9. Illustrates Aluminum at different loads.

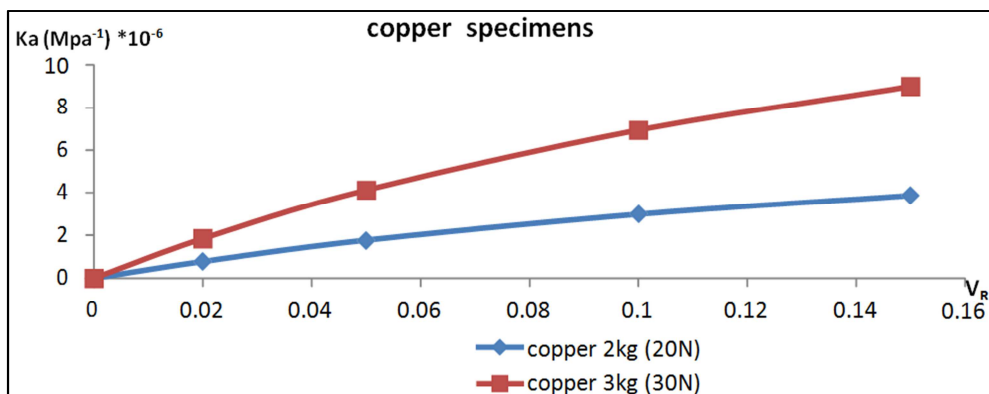


Figure 10. Illustrates copper at different loads.

It's important to compare between all specimens to show which of them the best one so these results shown in figure

11. It's noticeable in this figure that at different (VR) the lowest (K_a) is Aluminum specimen but the largest one is

copper so we can conclude that the best filler in case of wear resistance is aluminum specimen.

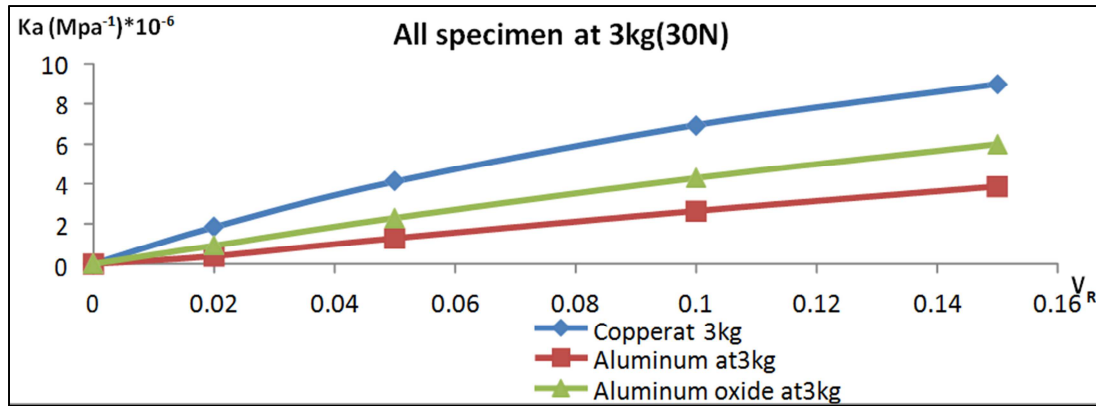


Figure 11. Illustrate all specimens under wear test at (30N).

As shown from wear and stiffness test copper represent the best stiffness factor for all VR and this represents good property but according to wear resistance copper also give highest value so this make from it not the best material for this work purpose. Aluminum show the best result for wear resistance but it's the declined material in stiffness for all VR and this exclude it for our purpose. (Al_2O_3) gives good performance in each of two tests for all VR as shown in Tables 3, 4.

Table 3. Illustrate comparison between (Al_2O_3) and Copper.

%Ka (for 3kg (30N)) (Ka specimen) / (Ka Aluminum)			
VR	(Cu/AL)	(Al_2O_3 /AL)	(AL/AL)
0	0.00	0.00	0.00
0.02	4.72	2.36	1
0.05	3.19	1.78	1
0.1	2.62	1.62	1
0.15	2.32	1.55	1

Table 4. Illustrate comparison between (Al_2O_3) and Aluminum.

% α stiffness factor (α specimen/ α copper)			
VR	(Cu/Cu)	(Al_2O_3 /Cu)	(AL/Cu)
0	0	0.00	0.00
0.02	1	0.93	0.78
0.05	1	0.96	0.90
0.1	1	0.98	0.93
0.15	1	0.95	0.92

As shown in Table 3 shows that Al_2O_3 has percent (%1.55) but Cu (%2.32) at VR (0.15) also this percent of Al_2O_3 less than Cu for all VR and this mean the wear resistance of Al_2O_3 is better than Cu. As shown in table 4 illustrates that Al_2O_3 has percent (0.95) but AL (0.92) at VR (0.15) also this percent of Al_2O_3 less than AL for all VR. It's noticeable that this difference reaches it max at VR (0.02) and it min at VR (0.15) but also still Al_2O_3 is better than AL as it has higher stiffness coefficient higher than AL so it can be concluded that Al_2O_3 has properties better than Cu and AL in combined features (stiffness and wear resistance).

3.3. Optimization of VR Percent

As the relation between stiffness and VR represent linear relation optimization will not add new result as the maximize stiffness factor will show that the best value of VR will be (15%) for all specimens. Wear rate coefficient also gives nearly linear relation so there is no expected result by optimization. So in this part new function putted under optimization by genetic algorithm.

Objective function will be MAX [$y_3 = w_1y_1 + w_2y_2$]

As y_1 represent the stiffness coefficient (α) and V% relation Y_2 represent the wear rate constant (Ka) and VR relation.

W 1, W2 represent weighted coefficients and after a lot of trials they had been chosen.

=0.5 and represents some of results represented in table 5.

Table 5. Illustrate of maximization process.

Specimen	Value of VR for maximize y_3	Value of y_3
copper	15%	14.43
Aluminum oxide	15%	15.432

As shown in this table shown that max value of VR is 15% so the results are expected in this range of VR that started from (0 to 15%). Mat lab code for optimization.

```

Clear;clc; Lb=[0];
Ub=[0];
Nvar=1;
[X,fval]=ga (@combined A, Nvar,[],[],[],[]); [X,fval]=
ga (@combined A,Nvar);
Function Y3= combined (VR)
Y1= (%it will depend on function from given data%)
Y2= (%it will depend on function from given data%)
YY3=0.5Y1+0.5Y2
Y3=1/ YY3;
END

```

4. Conclusion

It can be concluded from this experimental work that:-

- 1) Increasing volume ratio (VR) of fillers that mixing with silicone rubber leads increasing composite stiffness especially higher density fillers has higher stiffness coefficient.
- 2) Higher density filler materials has higher wear rate coefficient so it has lowest wear resistance.
- 3) For certain sliding distance in wear test increasing load leads to increase wear rate coefficient for all specimen and for all VR.
- 4) Aluminum oxide is more compatible for (LSR) matrix also it has suitable features according to stiffness and wear resistance so it's perfect choice for rubber projectile balls for heat exchanger.

5. Recommendations

Studying adding nano particles of Aluminum oxide and (composite material between copper and Aluminum) to (LSR) and increasing volume ratio to (50%) or higher also studying micro structure analysis for all specimens.

Acknowledgements

Special thanks to Ain shams university for giving me permission to use labs and test machines.

References

- [1] J. J. Park, J. Y. Lee, and Y. G. Hong, "Effects of vinylsilane-modified nanosilica particles on electrical and mechanical properties of silicone rubber nanocomposites," *Polymer (Guildf)*, vol. 197, no. April, p. 122493, 2020, doi: 10.1016/j.polymer.2020.122493.
- [2] N. A. Nordin, F. M. Yussof, S. Kasolang, Z. Salleh, and M. A. Ahmad, "Wear rate of natural fibre: Long kenaf composite," *Procedia Eng.*, vol. 68, pp. 145–151, 2013, doi: 10.1016/j.proeng.2013.12.160.
- [3] R. Kohli, *Applications of Projectiles for Nonaqueous Cleaning of Interior Surfaces of Tubes*, vol. 11. Elsevier Inc., 2019.
- [4] M. R. Jalalirad, M. S. Abd-Elhady, and M. R. Malayeri, "Cleaning action of spherical projectiles in tubular heat exchangers," *Int. J. Heat Mass Transf.*, vol. 57, no. 2, pp. 491–499, 2013, doi: 10.1016/j.ijheatmasstransfer.2012.10.071.
- [5] A. Grard, L. Belec, and F. X. Perrin, "Characterization and evaluation of primer formulations for bonding silicone rubber to metal," *Prog. Org. Coatings*, vol. 140, no. October 2019, p. 105513, 2020, doi: 10.1016/j.porgcoat.2019.105513.
- [6] M. S. Abd-Elhady and M. R. Malayeri, "Impact of hardness and surface texture on cleaning action of various projectiles," *Chem. Eng. Res. Des.*, vol. 94, pp. 153–163, 2015, doi: 10.1016/j.cherd.2014.07.022.
- [7] M. R. Jalalirad and M. R. Malayeri, "a Criterion for the Selection of Projectiles for Cleaning Tubular Heat Exchangers," vol. 2013, pp. 332–338, 2013.
- [8] D. P. Ross, P. A. Cirtog, Z. Cuckovic, G. Bridges, M. Crocker, and C. Dirks, "Energy Savings From an Automatic Tube Cleaning System (Atcs)," *Heat Exch. Fouling Clean.* – 2017, pp. 221–227, 2017.
- [9] J. L. Lin, S. M. Su, Y. B. He, and F. Y. Kang, "Improving the thermal and mechanical properties of an alumina-filled silicone rubber composite by incorporating carbon nanotubes," *Xinxing Tan Cailiao/New Carbon Mater.*, vol. 35, no. 1, pp. 66–72, 2020, doi: 10.1016/S1872-5805(20)60476-0.
- [10] P. Song, J. Song, and Y. Zhang, "Stretchable conductor based on carbon nanotube/carbon black silicone rubber nanocomposites with highly mechanical, electrical properties and strain sensitivity," *Compos. Part B Eng.*, vol. 191, no. January, p. 107979, 2020, doi: 10.1016/j.compositesb.2020.107979.
- [11] I. Madanhire, I. Zimba, and C. Mbohwa, "Improving self-cleaning system for de-fouling thermal power plant heat exchangers: Case study," *Proc. Int. Conf. Ind. Eng. Oper. Manag.*, vol. 2018, no. JUL, pp. 3042–3054, 2018.
- [12] T. L. M. Morgado, H. Navas, and R. Brites, "Wear study of Innovative Ti-Ta alloys," *Procedia Struct. Integr.*, vol. 2, pp. 1266–1276, 2016, doi: 10.1016/j.prostr.2016.06.162.
- [13] Hanan Al-Ghamd, "Impact of WO₃-Nanoparticles on Silicone Rubber for Radiation Protection Efficiency," *Protection Efficiency. Materials* 2022, 15, 5706. <https://doi.org/10.3390/ma15165706>
- [14] R. Kleinebrahm, "Mechanical Online System for Cleaning Heat Exchanger Tubes By Sponge Rubber Balls (Taprogge-System)," pp. 240–247, 2017.
- [15] C. Dearnitt, R. Rothon, and R. Consultants, "Encyclopedia of Polymers and Composites," *Encycl. Polym. Compos.*, no. 1991, pp. 1–19, 2014, doi: 10.1007/978-3-642-37179-0.