INTERNATIONAL JOURNAL OF
ENERGY AND ENVIRONMENT

Volume 12, Issue 2, 2021 pp.103-114
Journal homepage: www.IJEE.IEEFoundation.org

Enhancement of Desulfurization Process of Gray Cast Iron by using Different Concentrations and Materials

Ali A. Mnati, Kadhim K. Resan

Materials Engineering Department, College of Engineering, Mustansiriyah University, Iraq.

Received 5 Aug. 2021; Received in revised form 20 Sep. 2021; Accepted 25 Sep. 2021; Available online 1 Nov. 2021

Abstract
This research aims to best of the desulfurisation process through crucible furnace using waste oil motor. The best of desulfurisation process has been studied in crucible furnace of the melting shop with respect to the amount of desulfurising agent, control of carbon, and the temperature as well as the composition and the sulfur content. The results refer to the desulfurisation efficiency of calcium carbide is lower compared to burnt lime. The latter as well as desulfurisation, also has the ability to deoxidize and eliminate of oxygen that has a negative effect on the cast product. In this research, a study of recycling gray cast iron to purity gray cast iron and its effect on mechanical properties. Four kilograms (4.0 Kg) scrap were charged crucible furnace of ten kilograms (10.0 kg) capacity, where furnace using of waste motor oil for scrap heating and melting. The scrap in crucible furnace was heated to a temperature of 1400 °C and inserted thermocouple to monitor the temperature. For desulphurization, 0.2 kg calcium carbide (CaC_2) and burnt lime (CaO) were added to the molten in the furnace at 1400 °C melt. Then, ladle was used to eliminate of slag on the surface of the molten scrap resulting from desulfurizing agent.

Keywords: Desulfurisation; Burnt lime; calcium carbide; Scrap; Gray cast iron; Hardness; Strength.

1. Introduction
Sulphur is considered as an undesirable impurity of cast iron because it lowers the mechanical properties and contributes to many defects. The sulphur level in cast iron depends on its level in raw materials, on its removal from the metal before or during cast iron making operation. The present trend is for the user to demand lower sulphur levels while the oil-fired crucible furnace uses waste oil motor of increasing sulphur content. The fluctuations in the sulphur content of oil-fired crucible furnace iron from one cast to another is also a problem that requires some form of sulphur control. For the purpose of lowering the sulphur level in hot metal for steelmaking, it is desirable to study various methods of desulphurization of cast iron outside the blast furnace [1]. Over the past few decades, the demand for grey cast iron worldwide has increased at a rapid rate, along with the increase in the quality of grey cast iron. Grey cast iron producers are required to maximize productivity, reduce production interruptions, and maintain high quality standards while minimizing costs all the time. Modern metallurgy of grey cast iron is directed primarily to improving the quality, effectiveness and competitiveness of its production. One of the main ways for improving the quality of grey cast iron is to reduce its sulphur content. Sulphur is one of the most harmful impurities in

grey cast iron recycling process, affecting the internal and surface quality, effect of sulphur on grey cast iron,

- Formation of unwanted sulphides that enhance granular weaknesses and cracks in grey cast iron during solidification.
- It reduces the melting point and inters granular strength.
- Sulphur contributes to the brittleness of grey cast iron. Therefore, acts as stress concentration site in grey cast iron, [2].

There are many researchers who have presented studies on desulfurisation of gray cast iron, such as, Gamal M. El-Kady et al, had investigated the most significant parameters that have a great impact on the desulphurization process in term of energy and efficiency [2]. Annika Yang had studied the basic concepts about the desulphurization process of hot metal in reality [3]. E. T. T Urkdogan and L. J. Mart Onik had studied the utilization of burnt lime in desulfurisation [4]. Frank N. H. Schrama et al., had studied an optimal balance between maximizing sulphur removal capacity and minimizing iron losses [5]. Oyetunji Akinlabi and OMOLE S.O.had investigated desulfurise to from gray cast iron for the purpose of producing ductile iron[6]. In this study is to recycle gray cast iron with crucible furnace that the manner working encourages the pickup of sulfur by an iron molten, and in which it is gray cast iron utilized as scrap. This is because raise sulfur percent (up to about 0.179 %) is present in the scrap after recycling and pick up of sulfur is imminent during with by waste motor oil for melting, so the grey cast iron would treated with desulfurise agent to reduce the sulphur percent to suitable content in cast iron product. The aim of this project is to study the engineering practicality of the following materials for desulfurisation,

I. Adding calcium carbide (CaC_2) and burnt lime (CaO) to a grey cast iron melt with oil-fired crucible furnace.
II. Grey cast iron has become a necessity in the industrialized nations due to its numerous properties, among which are: good castability and low cost of production. Recycling of grey cast iron and desulphurize of grey cast iron scrap by use oil-fired crucible furnace to produce low sulphur grey cast iron will maintain mechanical properties and help small and medium scale enterprises to achieve and sustain industrial growth.

The limitations of the work and the results obtained: Composition control are difficult to control. Also as a result of utilization of waste motor oil as fuel by the furnace used, increase in sulphur pick up in the melt is a sure phenomenon; the charge materials, fuel and product of combustion are all in contact with each other in this system.

2. Desulfurization Technologies

Desulfurisation was analyzed to ensure whether equilibrium is established and to determine the reactions which equilibrate. Desulfurisation can be considered through two successive reactions,

- The sulphur exchange between iron and slag,

$$(S) + [CaO] \rightleftharpoons [CaS] + 1/2O_2 \tag{1}$$

- The deoxidation reaction which may be one of the following,

$$(C) + 1/2O_2 \rightleftharpoons CO \tag{2}$$

$$(Si) + O_2 \rightleftharpoons SiO_2 \tag{3}$$

$$(Mn) + {}^{1}/2O_2 \rightleftharpoons MnO \tag{4}$$

$$(Fe) + 1/2O_2 \rightleftharpoons FeO \tag{5}$$

These reactions are in decreasing order of ability to deoxidize and hence, when combined with Equation (2) tend to desulphurize. In desulphurization, the molten cast iron is treated in successive steps by adding highly basic materials such as calcium carbide (CaC_2), burnt lime (CaO) or soda ash (Na_2CO_3) to the molten in especially ladles for removal of oxygen and sulphur (see Table 1). The calcium compounds used for desulphurization are calcium carbide and burnt lime. Calcium carbide is the more common agent. The desulphurization reaction occurs between solid calcium carbide and liquid cast iron at the surface of the calcium carbide releasing carbon and producing solid calcium sulphide (CaS). Calcium sulphide has a melting point 2450 ^{o}C and specific gravity 2.50. The slag is granular, easily eliminated from the metal surface and does not attack ladle refractories extensively. Table 1 shows the characteristics of various desulphurizing agents.

The reaction is exothermic and results in smaller temperature losses than with other desulphurizer. Only small changes in carbon, silicon and manganese accompany desulphurization. The efficiency of desulphurization depends on the total calcium carbide surface area presented to the liquid iron and the rate of sulphur transport to the surface. The rate of sulphur transport to the surface depends on the sulphur content of the iron. Parameters influencing efficiency are degree of stirring, dwell time, injection rate and calcium carbide particle size [7].

Table 1. The characteristics of various desulphurizing agents, [7].

Factor	Calcium carbide CaC_2	Burnt lime CaO	Soda ash Na_2CO_3
Slag produced	Granular- easy to remove	Granular-easy to remove	Very fluid- complete removal difficult
Fume	Very little	Very little	Appreciable-extraction essential
Temperature loss	Small- exothermic reaction	Large	Large
Silicon loss	Not significant	Not significant	UP to 0.3 %
Storage requirements	To comply with statutory regulation	Keep dry	Keep dry
Refractories	Not important	Preferably basic	-------------

Many techniques are available for stirring (see Figure 1). The shaking ladle provides stirring by vessel movement. The ladle and its contents are supported in framework and subjected to a horizontal gyratory motion that causes efficient mixing of the molten iron and desulphurizing agent, usually CaC_2 and sometimes CaO. The shaking ladle can desulphurize from 2 to 60 tons of iron in a single treatment and useful for preparing base metal in ductile iron production. Other techniques achieve metal slag contact without ladle movement. In mechanical stirring an electrically driven stirring devices, comprising a rotary refractory paddle which is lowered into the ladle to mix the molten iron with a desulphurizing agent. Up to 50 tons of iron can be desulphurize in single treatment. Temperature losses are small and little metal splashing occurs. Other technique use gas (compressed air, N_2 or natural gas) to stir the liquid iron. The porous plug process, nitrogen or compressed air is blown through a porous refractory plug in the ladle bottom, creating turbulence to ensure intimate mixing of the molten metal and the desulphurizing agent – usually calcium carbide. This method is particularly suitable for small foundries, mainly for ductile iron production. Up to 10 tons of iron can be treated at low cost. Injection technique. The desulphurizing is metered into a gas flow by powder dispenser and injected through a refractory lance immersed in the molten iron. This method is used in the USA for ductile iron production and for reducing the sulphur content of grey, but other processes are generally preferred because the lances require frequent maintenance and injection blockage problems can arise. Direct tapping technique, the desulphurizing agent is placed in the ladle bottom and molten iron tapped on to the agent. Up to 50 % of the sulphur can be removed by this method, although results are not always reproducible. Only the use of Na_2CO_3 will produce a very significant decrease in sulphur content, Na_2CO_3 does, however produce a very fluid slag which must be coagulated and removed. Unless great care is taken, soda ash slag defects can arise in the casting [8].

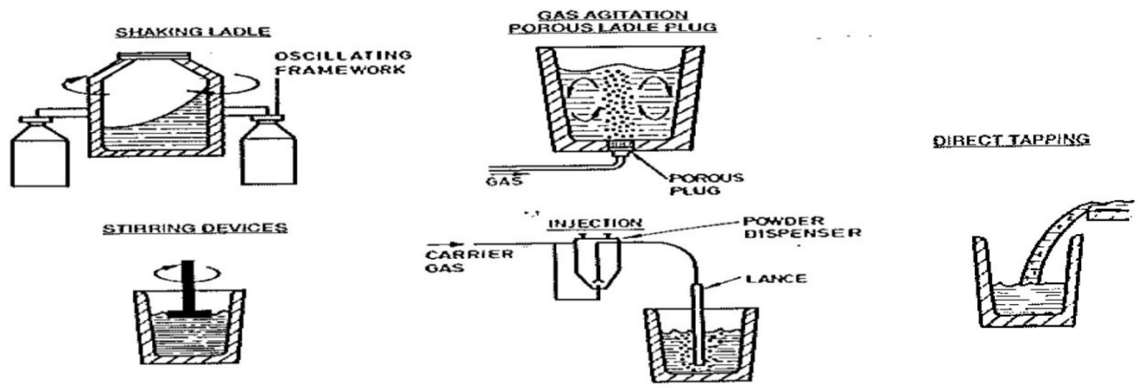

Figure 1. Techniques of ladle desulphurization, [8].

3. Experimental Work

3.1 Materials

Materials used in this work are: gray cast iron cylinder automobile engine was used as scrap, calcium carbide (CaC_2) and burnt lime (CaO) used as desulphuriser.

3.2 Equipment

- Crucible furnace (ten kilograms) capacity for melting the scrap.
- Waste motor oil was used for heating.
- Thermocouple with temperature controller to monitor the temperature, as shown.
- Spectrometer was used for inspection the chemical analyses.
- Wooden cylindrical pattern of diameter 20 mm by 200 mm length was used to prepare sand mould made of silica sand.
- The sand mould used was prepared by adding (5 % bentonite) as a binder and (5 % water) into silica sand according to [9]. The mould was prepared using sand round the pattern, to create a cavity upon which the molten metal was poured after the withdrawn of pattern from the sand.

3.3 Methods

The following are the techniques used in carrying out the research study,

I. Chemical Analysis, The sample scrap was analyzed using spectrometer to determine a chemical composition of the elements present in them. Spark test was performed on each sample at the head and at the middle point, and reading was taken and recorded as shown in Table 2.

Table 2. Composition of sample scrap.

Elements	C	Si	Mn	P	S	Fe
% Compositions	3.79	1.82	0.63	0.12	0.037	Balance

II. Melting and Casting, Pieces with size of (6-12 cm) scrap was putted in the crucible. Four kilograms (4.0 Kg) scrap were charged crucible furnace of ten kilograms (10.0 kg) capacity, where furnace using of waste motor oil for scrap heating and melting. The scrap in the oil-fired crucible furnace was heated to a temperature of 1400 °C and inserted thermocouple with temperature controller to monitor the temperature. For desulphurization, 0.2 kg calcium carbide (CaC_2) and burnt lime (CaO) were added to the molten in the furnace at 1400 °C melt. Then, ladle was used to eliminate of slag on the surface of the molten scrap resulting from desulfurizing agent. Thereafter, the treated molten was poured into the prepared mould immediately after the completion of the two treatments at a temperature higher than 1350°C to ensure the removal of gaseous cavities,. As shown in table 3 in details distinguish of all additives that were used in this study, Figure 2.

Figure 2. Standard test sample.

Table 3. Theoretical charge calculation.

No	Charge (Kg)	CaO% of charge weight	CaC_2% of charge weight
A	4	-	-
B	4	-	5
C	4	5	-

III. Samples Preparations, The sample scrap and the sample product were prepared for mechanical, chemical analysis, [10-25]. The mechanical tests were done to inspect the tensile, impact and Brinell hardness properties of the samples. Samples were machined using lathe and milling machine.

IV. Tensile inspection, tensile specimen was machined using lathe machine, according to universal tester specification of (50 mm) gauge length which fits into testing machine. The tensile test specimen shown in Figure 3 was fixed on the universal testing machine at the jaws one end immovable and the other movable. The machine was then operated, which pulled at constant rate of extension and the tensile test performed in accordance with ASTM E8/E8M-13a standards [26]. The tensile test was performed at room temperature and a cross-head speed of 2 mm/min. where, a three samples test for each sample types were used to calculated the tensile properties, [27-42].

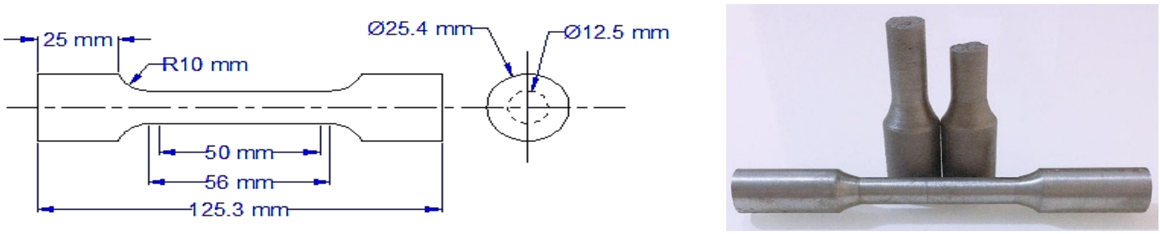

Figure 3. A standard tensile sample.

V. Impact inspection, Charpy impact inspection was performed with notched specimen performed in accordance with ASTM E23, according to the research Tanzim Nasir [43]. The impact test specimen shown in Figure 4, so, three samples were used for each test, and then using the average value to calculate the impact characterizations, [44-57].

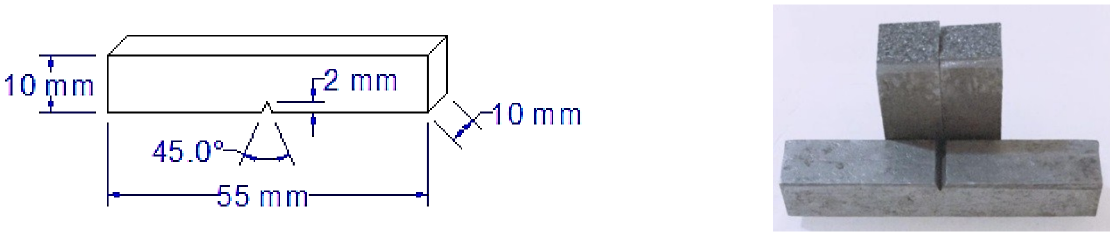

Figure 4. A standard Charpy impact specimen.

VI. Hardness inspection, Brinell hardness specimens were machined using milling machine from the scrap and the product. Samples were performed in accordance with ASTM E10 standards that conform to specification which fits into digital Brinell hardness inspector machine. The surface of the entire hardness inspect specimen was grinded using 200,400 and 1200 SiO_2 emery papers to make them flat and smooth, which using a three sample for each test to evaluate the average value for hardness properties for each sample types, [58-72].

4. Results and discussion

The tensile analysis was shown in Table 4 of sample scrap and sample product A, B, C respectively. The tensile, elongation, impact and hardness values are as presented in Table 4. The result of the composition analysis was as presented in Table 5. The product from melt and casting was satisfactory good with no defect.

Table 4. Tensile analysis, impact and hardness values of scrap and sample (G).

Sample	UTS (MPa)	BHN	Impact (J)
A	248	400.3	5.66
B	236	372.6	5.37
C	248	387.6	5.95

Table 5. The composition analysis of samples.

Sample	Chemical Properties								
	C%	Si%	Mn%	P%	S%	Ni%	Mo%	Cr%	Fe%
A	5.22	1.73	0.19	0.060	0.179	0.026	0.002	0.027	Bal.
B	5.22	2.07	0.19	0.047	0.112	0.024	0.013	0.023	Bal.
C	4.07	1.38	0.77	0.052	0.054	0.027	0.005	0.029	Bal.

4.1 Composition analysis and desulphurization

The result obtained from the composition of the used scrap analyzed in Table 5 indicated that C% of 3.97% was increased to 5.22 %, 5.22 % and 4.07 % in samples A, B and C respectively (see Table 5), this represents a total carbon raise of 26.0 %, 31.0% and 1.0% in samples A, B and C respectively. Although the oxidation was due to the nature of the mode of operation of crucible furnace, in which the fuel, charges and the products of combustion are all in contact with themselves. This was supposed to cause a loss of carbon, but carbon percent gained exceeds carbon percent loss due to the melting method. As a result, there was such a large increase in samples A and B.

In sample C, due to the treated of the molten by added a desulphurizer agent (5%CaO) of scrap weight, whereby amount of the carbon is lost by its react with oxygen and released carbon dioxide. In contrast to, a desulphurizer agent (5%CaC_2) of scrap weight was added in sample B, the carbon remained in the molten and is not released as gas or slag, so the carbon percent was larded. As a result of the low purity of the scrap used and the processing method in the oil-fired crucible furnace high sulphur content up to 0.1 % was still found in the casting. In sample B, treated of the molten by added a desulphurizer agent (5% CaC_2) of scrap weight, S% of the used scrap (0.179%) was decreased to 0.112 %. This S% dropped was very little, not within the specified range that guarantees better mechanical properties to gray cast iron.while, in sample C was added a desulphurizer agent (5%CaO) of scrap weight, S% of the used scrap (0.179%) was decreased to 0.054 %.

ISSN 2076-2895 (Print), ISSN 2076-2909 (Online)

4.2 Tensile strength

The results were obtained in Table 4 from tensile analysis showed the ultimate tensile strength obtained for sample A was 248MPa and sulphur percent 0.179% without added a desulphurizer agent, sample B was 236MPa and sulphur percent 0.112% with added (5%CaC_2) while for sample C was 248MPa and sulphur percent 0.054% with added (5%CaO) which is significantly alright. The ultimate tensile strength obtained for sample C was 248MPa while for sample B is 236MPa which is significantly alright.

4.3 Brinell hardness

The average hardness obtained in sample A was 400.3 HB, in sample B was 372.6 HB and in sample C was 387.6 HB as shown in Table 4.

5. Conclusions

Treated of the molten by added a desulphurizer agent (5%CaC_2) and (5%CaO) were carried out on grey cast iron. The resulting hardness and tensile was investigated.

The results show that:

1. Burnt lime (CaO) as a desulphurizer in sample B

   Burnt lime has been found to be capable of removing sulphur from grey cast iron; the desulphurization proceeds at a high rate. The sulphur level in a grey cast iron molten depends on initial sulphur and type melting furnace. At crucible furnace that the mode of firing encourages the pickup of sulphur by the metal, and in which it is grey cast iron utilized as scrap. This is because high sulphur (up to about 0.179 %) is present in the scrap after recycling and pick up of sulphur is imminent in the course of using waste motor oil for melting, so grey cast iron recycling would have undergone desulphurization with(CaO) to reduce the sulphur content to appropriate level(0.054% S) in the cast product C.
2. Calsium carbide (CaC_2) as a desulphurizer in sample B

   Calcium carbide was found that it desulfurizer is inappropriate for cast iron that contains a high carbon percent in it as a result of increasing the percentage of carbon to more than 5% due to the liberation of carbon as a result of the following reaction ($\mathrm{CaC_2(s)} + \underline{\mathrm{S}} \leftrightarrow \mathrm{CaS(s)} + 2\underline{\mathrm{C}}$), where the carbon remains in the molten according to Annika Yang [7]. Also, sulphur percent removal in a sample B very low model was 0.112% S.
3. Improved ultimate tensile strength (248 MPa) and impact (5.95 J) in sample C after treated molten with (CaO).

Acknowledgements

The authors would like to express their gratitude to the staff of Mustansiriyah University (www.upomustansiriyah.edu.iq) Bagdad, Iraq, for their assistance with this project.

Reference

[1] Jean Limoges 'Studies on Desulphurisation of' Pig Iron Hith Sodium, Rare. Earth Metals and Slags Rich in Cerium Oxide' M.Sc. Thesis University of Montreal, 1969.

[2] G. M. El-Kady, M. K. El-Fawkhry, A. E. Merdach 'Optimization of Desulfurization Process Through Studying the Ladle Refiningfurance Parameters' Al Azhar Buletin of Science, Vol. 25, No. 3, 2014.

[3] A. F. Yang 'A pre-study of Hot Metal Desulphurization (Issue October)' Royal Institute of Technology, 2012.

[4] E. T. Turkdogan, L. J. Martonik 'Sulfur Solubility in Iron-Carbon Melts Coexistent with Solid Cao and Cas' In Transactions of the Iron and Steel Institute of Japan, Vol. 23, No. 12, pp. 1038–1044, 1983.

[5] Frank N. H. Schrama, Elisabeth M. Beunder, Sourav K. Panda, Hessel-Jan Visser, Elmira Moosavi-Khoonsari, Jilt Sietsma, Rob Boom, Yongxiang Yang 'Optimal hot metal desulphurisation slag considering iron loss and sulphur removal capacity part I fundamentals' Ironmaking & Steelmaking, Vol. 48, No. 1, 2021.

[6] Oyetunji Akinlabi, S. O. Omole ‘Evaluation of Ductile Iron Produced using Rotary Furnace with Variable Compositions of Magnesium Addition’ International Journal of Science and Advanced Technology, Vol. 1, No. 9, 2011.
[7] C. M. Hansson ‘Cast iron technology’ Materials Science and Engineering: A, Vol. 114, 1989.
[8] J. M. Coudure, G. A. Irons ‘The Effect of Calcium Carbide Particle Size Distribution on the Kinetics of Hot Metal Desulphurization’ ISIJ International, Vol. 34, No. 2, 1994.
[9] Group Company A BCIRA ‘Desulphurization of molten cast iron’ 1995.
[10] Muhsin J.Jweeg, Kadhim K. Resan, Muhanad N. Mohammed ‘Design and Manufacturing of A New Prosthetic Low Cost Pylon for Amputee’ Journal of Engineering and Development, Vol. 14, No. 4, 2010.
[11] Muhsin J. Jweeg, Kadhim K. Resan ‘Study of Creep-Fatigue Interaction in A Prosthetic Socket Below Knee’ ASME 2012 International Mechanical Engineering, 2012.
[12] Muhsin J. Jweeg, Muhannad Al-Waily ‘Determination of Inter-Laminar Shearing Stresses Using a Suggested Analytical Solution in the Composite Laminated Plates’ International Journal of Mechanical Engineering, Vol. 2, No. 5, 2013.
[13] Mohsin Abdullah Al-Shammari, Muhannad Al-Waily ‘Theoretical and Numerical Vibration Investigation Study of Orthotropic Hyper Composite Plate Structure’ International Journal of Mechanical & Mechatronics Engineering, Vol. 14, No. 6, 2014.
[14] Muhsin J. Jweeg, Kadhim K. Resan, Ali Abdulameer Najm ‘Improving Fatigue Life of Bolt Adapter of Prosthetic SACH Foot’ Journal of Engineering, Vol. 20, No. 3, 2014.
[15] Ikram R. Abd Al-razaq, Kadhim K. Resan ‘Design and Manufacturing of Fast Prosthetic below Knee Socket’ ASME International Mechanical Engineering Congress and Exposition, 2015.
[16] Muhannad Al-Waily ‘Analytical and Numerical Buckling and Vibration Investigation of Isotropic and Orthotropic Hyper Composite Materials Structures’ International Energy and Environment Foundation, 2015.
[17] Shireen Challoobi, Kadhim Resan and Yasir Ibrahim ‘Stress Relaxation and Creep Effect on Polypropylene below Knee Prosthetic Socket’ Journal of JSEM, Vol. 15, pp. 93-98, 2015.
[18] Zainab Yousif Hussien, Kadhim Kamil Resan ‘Effects of Ultraviolet Radiation with and without Heat, on the Fatigue Behavior of Below-Knee Prosthetic Sockets’ International Journal of Mechanical and Production Engineering Research and Development, Vol. 7, No. 6, 2017.
[19] Muhsin J. Jweeg, Muhannad Al-Waily, Ahmed K. Muhammad, Kadhim K. Resan ‘Effects of Temperature on the Characterisation of a New Design for a Non-Articulated Prosthetic Foot’ IOP Conference Series: Materials Science and Engineering, 2nd International Conference on Engineering Sciences, Vol. 433, 2018.
[20] Ehab N. Abbas, Muhsin J. Jweeg, Muhannad Al-Waily ‘Analytical and Numerical Investigations for Dynamic Response of Composite Plates Under Various Dynamic Loading with the Influence of Carbon Multi-Wall Tube Nano Materials’ International Journal of Mechanical & Mechatronics Engineering, Vol. 18, No. 06, pp. 1-10, 2018.
[21] Ali Munther Jaafar, Muhannad Al-Waily ‘Calculation of Elastic Deformation Under the Influence of High Velocity Impact on Composite Plate Structures’ International Journal of Energy and Environment, Vol. 10, No. 06, pp. 359-372, 2019.
[22] Ehab N. Abbas, Muhsin J. Jweeg, Muhannad Al-Waily ‘Fatigue Characterization of Laminated Composites used in Prosthetic Sockets Manufacturing’ Journal of Mechanical Engineering Research and Developments, Vol. 43, No. 5, pp. 384-399, 2020.
[23] Abeer R. Abba, Kadhim A. Hubeatir, Kadhim K. Resan ‘The Effect of Laser Energy on the Rate of Corrosion for Ni46-Ti50-Cu4 Shape Memory Alloy’ IOP Conference Series: Materials Science and Engineering, INTCSET, Vol. 1094, 2021.

[24] Esraa A Abbod, Kadhim K Resan 'Review on the Interface Pressure Measurement for Below Knee Prosthetic Socket' IOP Conference Series: Materials Science and Engineering, 1st International Conference on Sustainable Engineering and Technology, Vol. 1094, 2021.

[25] Emad Kadum Njim, Sadeq H. Bakhy, Muhannad Al-Waily 'Analytical and Numerical Investigation of Buckling Behavior of Functionally Graded Sandwich Plate with Porous Core' Journal of Applied Science and Engineering, Vol. 25, No 2, pp. 339-347, 2022.

[26] ASTM E8 / E8M-13 'Standard Test Methods for Tension Testing of Metallic Materials' ASTM International, West Conshohocken, PA, 2013.

[27] Muhsin J. Jweeg, Ahamed A. Al-Beiruti, Kadhim K.Al-Kinani 'Design and Analysis of New Prosthetic Foot' Al- Khwarizmi Engineering Journal, Vol. 3, No. 1, pp. 12-25, 2007.

[28] Muhsin J. Jweeg, Ali S. Hammood, Muhannad Al-Waily 'Experimental and Theoretical Studies of Mechanical Properties for Reinforcement Fiber Types of Composite Materials' International Journal of Mechanical & Mechatronics Engineering, Vol. 12, No. 4, 2012.

[29] Muhsin J. Jweeg, Kadhim K. Resan, Ali Abdulameer Najim 'Improving Fatigue Life of Bolt Adapter of Prosthetic SACH Foot' 8th International Symposium on Advanced Science and Technology in Experimental Mechanics, 2013.

[30] Noor k. Faheed, Kadhim k. Resan, Mohammed H. Ali 'Effect of Temperature on Buckling of Composite Material Column' 10th International Symposium on Advanced Science and Technology in Experimental Mechanics, 2015.

[31] Muhannad Al-Waily 'Dynamic Analysis Investigation of Stiffened and Un-Stiffened Composite Laminated Plate Subjected to Transient Loading' International Energy and Environment Foundation, 2015.

[32] Ikram R. Abd Al-razaq, Kadhim Kamil Resan, Yasir Khalil Ibrahim 'Design and Manufacturing of Prosthetic below Knee Socket by Modular Sockwt System' Journal of Engineering and Development, Vol. 2, No. 2, 2016.

[33] Ahmed M. Hameed, Kadhim K. Resan, Khalid M. Eweed 'Study the Effect of Reverse Rotation Friction Stir Processing on the dissimilar aluminum alloys' Al-Nahrain Journal for Engineering Sciences, Vol. 20, No. 1, pp. 120-128, 2017.

[34] Muhannad Al-Waily 'Analytical and Experimental Investigations Vibration Study of Isotropic and Orthotropic Composite Plate Structure with Various Crack Effect' International Energy and Environment Foundation, 2017.

[35] Ameer A. Kadhim, Muhannad Al-Waily, Zaman Abud Almalik Abud Ali, Muhsin J. Jweeg, Kadhim K. Resan 'Improvement Fatigue Life and Strength of Isotropic Hyper Composite Materials by Reinforcement with Different Powder Materials' International Journal of Mechanical & Mechatronics Engineering, Vol. 18, No. 02, 2018.

[36] Jumaa S. Chiad, Muhannad Al-Waily, Mohsin Abdullah Al-Shammari 'Buckling Investigation of Isotropic Composite Plate Reinforced by Different Types of Powders' International Journal of Mechanical Engineering and Technology, Vol. 09, No. 09, pp. 305–317, 2018.

[37] Muhannad Al-Waily, Moneer H. Tolephih, Muhsin J. Jweeg 'Fatigue Characterization for Composite Materials used in Artificial Socket Prostheses with the Adding of Nanoparticles' IOP Conference Series: Materials Science and Engineering, 2nd International Scientific Conference of Al-Ayen University, Vol. 928, 2020.

[38] Muhannad Al-Waily, Mohsin Abdullah Al-Shammari, Muhsin J. Jweeg 'An Analytical Investigation of Thermal Buckling Behavior of Composite Plates Reinforced by Carbon Nano Particles' Engineering Journal, Vol. 24, No. 3, 2020.

[39] Ameer A. Kadhim, Esraa A. Abbod, Ahmed K. Muhammad, Kadhim K. Resan, Muhannad Al-Waily 'Manufacturing and Analyzing of a New Prosthetic Shank with Adapters by 3D Printer' Journal of Mechanical Engineering Research and Developments, Vol. 44, No. 3, pp. 383-391, 2021.

[40] Muhannad Al-Waily, Muhsin J. Jweeg, Mohsin Abdullah Al-Shammari, Kadhim K. Resan, Ayad M. Takhakh 'Improvement of Buckling Behavior of Composite Plates Reinforced with Hybrids Nanomaterials Additives' Materials Science Forum, Vol. 1039, pp. 23-41, 2021.

[41] Emad Kadum Njim, Muhannad Al-Waily, Sadeq H. Bakhy 'A Review of the Recent Research on the Experimental Tests of Functionally Graded Sandwich Panels' Journal of Mechanical Engineering Research and Developments, Vol. 44, No. 3, pp. 420-441, 2021.

[42] Emad Kadum Njim, Muhannad Al-Waily, Sadeq H Bakhy 'A Critical Review of Recent Research of Free Vibration and Stability of Functionally Graded Materials of Sandwich Plate' IOP Conference Series: Materials Science and Engineering, Vol. 1094, 2021.

[43] Tanzim Nasir 'Design of Heat Treatment for Production of Austempered Ductile Iron (ADI) With Targeted Automotive Applications' M.Sc. Thesis, Faculty of Graduate Studies, University of Windsor, 2011.

[44] Muhsin J. Jweeg, Muhannad Al-Waily 'Analytical Investigation of Time Dependent Tensional Loading of Stiffened and Un-Stiffened Composite Laminated Plates' International Journal of Mechanical and Production Engineering Research and Development, Vol. 3, No. 4, 2013.

[45] Mustafa Tariq Ismail, Muhsin Jabir Jweeg, Kadhim Kamil Resan 'Study of Creep-Fatigue Interaction in the Prosthetic Socket below Knee' Innovative Systems Design and Engineering, Vol. 4, No. 5, 2013.

[46] Muhsin J. Jweeg, Kadhim K. Resan, Ali Abdulameer Najm 'Study and Analysis of Failure Mechanism of Bolt Adapter in Prosthetic SACH Foot' Eng. & Tech. Journal, Vol. 32, Part A, No. 6, 2014.

[47] Kadhim Kamil Resan, Yasir Khalil Ibrahim, Shireen Hasan Challoob 'Stress Relaxation on Prosthetic Laminated Socket Materials' Journal of Engineering and Development, Vol.20, No. 3, 2015.

[48] Muhannad Al-Waily 'Analytical and Numerical Thermal Buckling Analysis Investigation of Unidirectional and Woven Reinforcement Composite Plate Structural' International Journal of Energy and Environment, Vol. 6, No. 2, 2015.

[49] Dania F. Abbas, Kadhim K. Resan, Ayad M. Takhakh 'Optimization of Ni-Ti-Cu shape memory effect using minitab program' International Journal of Energy and Environment, Vol. 7, No. 3, pp. 263-268, 2016.

[50] Kadhim K. Resan 'The effect of ultraviolet radiation on the modulus of stress relaxation of polypropylene prosthetic sockets' International Journal of Energy and Environment, Vol. 8, No. 6, pp. 491-500, 2017.

[51] Muhannad Al-Waily, Alaa Abdulzahra Deli, Aziz Darweesh Al-Mawash, Zaman Abud Almalik Abud Ali 'Effect of Natural Sisal Fiber Reinforcement on the Composite Plate Buckling Behavior' International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS, Vol.17, No.1, 2017.

[52] Abeer R. Abbas, Kadhim A. Hebeatir, Kadhim K. Resan 'Effect of Laser Energy on the Structure of Ni46–Ti50–Cu4 Shape-Memory Alloy' International Journal of Nanoelectronics and Materials, Vol. 11, No. 4, 2018.

[53] Mohsin Abdullah Al-Shammari, Muhannad Al-Waily 'Analytical Investigation of Buckling Behavior of Honeycombs Sandwich Combined Plate Structure' International Journal of Mechanical and Production Engineering Research and Development, Vol. 08, No. 04, pp. 771-786, 2018.

[54] Ehab N. Abbas, Muhannad Al-Waily, Tariq M. Hammza, Muhsin J. Jweeg 'An Investigation to the Effects of Impact Strength on Laminated Notched Composites used in Prosthetic Sockets Manufacturing' IOP Conference Series: Materials Science and Engineering, 2nd International Scientific Conference of Al-Ayen University, Vol. 928, 2020.

[55] Sumeia A. Mechi, Muhannad Al-Waily, Aseel Al-Khatat 'The Mechanical Properties of the Lower Limb Socket Material Using Natural Fibers: A Review' Materials Science Forum, Vol. 1039, pp. 473-492, 2021.

[56] Emad Kadum Njim, Sadeq H. Bakhy, Muhannad Al-Waily 'Analytical and Numerical Investigation of Free Vibration Behavior for Sandwich Plate with Functionally Graded Porous Metal Core' Pertanika Journal of Science & Technology, Vol. 29, No. 3, pp. 1655-1682, 2021.

[57] Zaman Abud Almalik Abud Ali, Ameer A. Kadhim, Rasha Hayder Al-Khayat, Muhannad Al-Waily 'Review Influence of Loads upon Delamination Buckling in Composite Structures' Journal of Mechanical Engineering Research and Developments, Vol. 44, No. 3, pp. 392-406, 2021.

[58] Kadhim K. Resan, Ali H. Al Hilli, Ali H., Al Hilli 'Design and Analysis of A New Prosthetic Foot for People of Special Needs' The Iraqi Journal For Mechanical And Material Engineering, Vol. 11, No. 2, 2011.

[59] Shaker S. Hassan, Khadim K. Resan, Akeel Zeki Mahdi 'Design and Analysis of Knee Ankle Foot Orthosis (KAFO) for Paraplegia Person' Eng. & Tech. Journal, Vol. 31, Part A, No. 8, 2013.

[60] Muhsin J. Jweeg, Kadhim K. Resan, Ali Abdulameer Najim 'Study and Analysis of the Faituge Failure (of Bolt Adapter) of Prosthetic Sach Foot' International Journal of Mechanical and Production Engineering Research and Development, Vol. 4, No. 2, 2014.

[61] Dania Abbas, Kadhim K. Resan, Ayad Takhakh 'Microstructure and Mechanical Properties of Ni-Ti-Cu Shape Memory Alloys Biomaterials' ASME International Mechanical Engineering Congress and Exposition, 2015.

[62] Muhannad Al-Waily, Zaman Abud Almalik Abud Ali 'A Suggested Analytical Solution of Powder Reinforcement Effect on Buckling Load for Isotropic Mat and Short Hyper Composite Materials Plate' International Journal of Mechanical & Mechatronics Engineering, Vol.15, No. 4, 2015.

[63] Muhsin J. Jweeg, Muhannad Al-Waily, Alaa Abdulzahra Deli 'Theoretical and Numerical Investigation of Buckling of Orthotropic Hyper Composite Plates' International Journal of Mechanical & Mechatronics Engineering, Vol.15, No. 4, 2015.

[64] Muhsin J. Jweeg, Muhannad Al-Waily 'Experimental and numerical analysis of cross-ply and angle-ply composite laminated plates having various shapes of cut outs' International Journal of Energy and Environment, Vol. 7, No. 6, 2016.

[65] Muhannad Al-Waily, Kadhim K. Resan, Ali Hammoudi Al-Wazir, Zaman Abud Almalik Abud Ali 'Influences of Glass and Carbon Powder Reinforcement on the Vibration Response and Characterization of an Isotropic Hyper Composite Materials Plate Structure' International Journal of Mechanical & Mechatronics Engineering, Vol.17, No.6, 2017.

[66] Abeer R. Abbas, Kadhim A. Hebeatir, Kadhim K. Resan 'Effect of Co2 Laser on Some Properties of Ni46Ti50Cu4 Shape Memory Alloy' International Journal of Mechanical and Production Engineering Research and Development, Vol. 8, No. 2, pp. 451-460, 2018.

[67] Mahmud Rasheed Ismail, Zaman Abud Almalik Abud Ali, Muhannad Al-Waily 'Delamination Damage Effect on Buckling Behavior of Woven Reinforcement Composite Materials Plate' International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS, Vol. 18, No. 05, pp. 83-93, 2018.

[68] Kadhim K. Resan 'Effect of repeated load on life of the PMMA molar denture' International Journal of Energy and Environment, Vol. 10, No, 4, pp. 231-236, 2019.

[69] Dania Fadhil Abbas, Kadhim Kamil Resan, Ayad M. Takhakh 'Microstructure, mechanical and corrosion properties of the 50%Ni-47%Ti-3%Cu shape memory alloy' IOP Conference Series: Materials Science and Engineering, 3rd International Conference on Engineering Sciences, Vol. 671, 2020.

[70] Muhsin J. Jweeg, H. A. Hamzah, Muhannad Al-Waily, Mohsin Abdullah Al-Shammari 'A Finite Element Simulation of Nano Effects on Stress Distribution in a Below Knee Prosthetic' 4th

International Conference on Engineering Sciences, IOP Conference Series: Materials Science and Engineering, Vol. 1067, 2021.

[71] Sumeia A. Mechi, Muhannad Al-Waily 'Manufacturing and mechanical behavior investigation of prosthetic below knee socket by using natural kenaf fiber' International Journal of Energy and Environment, Vol. 12, No. 1, pp. 45-62, 2021.

[72] Sumeia A Mechi, Muhannad Al-Waily 'Impact and Mechanical Properties Modifying for Below Knee Prosthesis Socket Laminations by using Natural Kenaf Fiber' 3rd International Scientific Conference of Engineering Sciences and Advances Technologies, Journal of Physics: Conference Series, Vol. 1973, 2021.