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WEAR RESISTANCE OF DIFFERENT TYPES OF CAST IRON USED IN GLASS BLOW MOULD

Kadhim Mijbel Mashloosh

Lecturer, Technical Engineering College –Baghdad

E-Mail: kadm52@yahoo.com

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ABSTRACT: - The aim of this work is to study the wear characteristics of different cast iron types which might be used as mould materials in glass blow molding. Wear testing rig was designed and developed to carry out the wear tests. Three types of gray cast iron with different chemical compositions were cast and heat treated, as well as samples taken (for comparison) from another two existing mould already being in use.

Samples for wear testing were taken from the prepared materials and abraded against an automobile friction brake pads. Sliding velocity, friction pressure and contact time were taken as test variables. Weight loss of the tested samples was measured after conducting the wear tests at 600 & 800 ^{0}C.

Cast iron with (2.98% C, 5.117% Si, and 1.39% Cu) showed the highest hardness in its as cast condition compared to the other types. It showed the best wear resistance after heat treatment (stress relief annealing).

Results also showed that some of the tested materials gave a good wear resistance at low temperature (up to 600 ^{0}C) but they lost their resistance at high temperature (up to 800 ^{0}C). It was concluded that hardness is not the only parameter that controls the wear resistance at high temperature.

Keywords: Cast iron, Wear resistance, Glass blow moulds.

1. INTRODUCTION

Gray cast irons because of their good resistance to wear, have been widely used in variety of mechanical systems for many years. They have used in piston rings, bearings, brakes, seals, glass mould and so forth [(1)].

Glass blow mould used on individual section machine consists of many parts working as group, as shown in Figure-1.

The quality of a glass container used in several applications depends on the nature of contact between hot glass and its metallic mould. The type of mould material and its surface conditions will affect the rate of production and costs, therefore the selection of proper mold material has a significant role in the glass industry. Many types of materials had been used during the past years, but nowadays cast irons are the most commonly used material for glass moulds. The wide range of properties, low cost and ease of fabrication (casting) makes the cast iron a suitable material. The addition of some alloying elements (ferrosilicon, cerium or magnesium) will lead to a better microstructure regarding the size, shape and distribution of graphite particles [(1, 2)].

Glass blow mould surfaces are exposed to damage as a result of wear, growth, thermal fatigue, etc. In order to recognize the performance of gray cast iron employed as a glass blow mould, wear test at high temperature is necessary to obtain true practical and reliable results. Most of commercial wear testing machines are used to carry out the test at room temperature, so the results will not resemble the wear of glass mould material at high temperature.

Cast iron has good resistance to oxidation, growth and scaling and much less tendency to distortion. High – carbon cast iron has a high thermal conductivity and a low modulus of elasticity giving marked resistance to thermal shock, but may have a coarse, open – grained surface with a poor initial finish and a tendency to deep oxidation as a result, together with poor wear resistance. Close – grained surface, however, can overcome these disadvantages [(3)].

The strength, hardness, wear resistance, temperature resistance, corrosion resistance, machinability and cast ability of irons may be improved by the addition of elements such as nickel, chromium, molybdenum, vanadium, copper and zirconium after suitable heat treatment.

The alloying cast iron with nickel decreases primary carbide stability and mildly improves strength, but high nickel content reduces thermal conductivity about (5 – 6%) for (1%) nickel addition. The molybdenum increases the resistance of glass mould to thermal checking and high temperature deformation also, it tends to increase thermal conductivity (7%) for (0.58%) molybdenum addition.

Nodular cast iron cannot be considered suitable for bottle moulds because of its relative low thermal conductivity which causes poor ability to extract heat from the product and that leads to reduce the glass production speed, but it is still suitable for the small bottles production. Wear resistance of glass mold at high temperature (molten glass temperature) will be affected by alloying elements (Cr, Mo, Ni) added in small amounts to the Cast Iron. This will cause an increase in the glass mold life [(4)].

Other investigations studied the effect of other additions like Cr and Mn on the wear resistance of gray cast iron, all concluded that the improvement in wear resistance was attributed to the formation of complex carbides (Cr_7C_3 $(FeMn)_3C$) which played a significant rule in enhancing the metallurgical and mechanical properties of the iron particularly when the iron is heat treated. The presence of graphite flakes can also reduce the wear [(5, 6, 7)].

Junichiro Yamabe, et al [8] developed a new method to evaluate thermal fatigue by a simulating high –speed braking test using an actual disc brake rotor made of gray cast iron. Results showed that increasing graph ite number in the microstructure improves thermal fatigue strength. The graphite number increases in proportion to the amount of nickel added. Cerium inoculation produces the similar effect to that of nickel addition.

G. Cueva, et al [9] studied the wear resistance of three different types of gray cast iron (gray iron grade250, high – carbon gray iron and titanium alloyed gray iron), which are used in automobile brake disc rotors (exposed to heating and cooling cycles similar to that happen for glass blow mould materials), and compared them with the results obtained with a compacted graphite iron using a truck brake pad as the abrader. Results show that compacted graphite iron reached greater mass losses than the three gray irons at any friction pressure applied.

Sugwon Kim [10] examined the behavior of compacted graphite cast iron at elevated temperatures to help facilitate its increased use in high temperature applications. Mechanical, wear and heat exposure tests were carried out. The tensile strength at elevated temperature was found to increase linearly within creasing nodularity % and pearlite %. In addition, the tensile strength was found to decrease within creasing temperature at the same nodularity % and pearlite % and the wear loss was found to decreases lightly with increasing nodularity % and pearlite %. At the same nodularity % and pearlite %, the wear increased with increasing temperature.

M.H Cho, S.J Kim [11], studied the friction characteristics using gray cast iron and automotive brake linings. The samples were manufactured to have different microstructures by changing the carbon equivalent and cooling speeds of melts and two different types of noncommercial brake linings (non-steel and steel-containing linings) were used as a counter material. Friction tests were performed one pad-on-disk type tribotester and particular emphases were given to the effect of graphite flakes and ferrite in the gray iron disks on fade phenomena and the level of the coefficient of friction. Peter J. Blau, Brian C. Jolly [12], examined how to determine whether the wear of brake lining material scan be measured in shorter-term laboratory tests, and if so, to determine to what extent the relative ranking of several lining materials' wear resistance depends on the method of testing. To investigate these issues, three commercial truck brake lining materials were worn against gray cast iron using three different laboratory-scale wear testing machines.

In this work wear tests at high temperature were conducted on prepared samples made of cast irons selected to be as blow mould materials. Cast Irons made especially for this work and those taken from real moulds from local companies, were tested on a specially designed rig for high temperature wear tests. The results regarding the prepared cast iron were encouraging.

2. EXPERIMENTAL WORK

Five samples of cast irons were used in this research as shown below:-

1) Nickel Molybdenum - alloyed cast iron (EF6), cut from a real glass blow mould (provided by OMCO – a Belgium company, a European leading glass mould maker).
2) Three groups of gray cast irons with different microstructures as a result of heat treatment and chemical compositions are produced for this research, named as material No. 1, 2 & 3. These materials were produced by sand casting as cylindrical rod's (53 mm in diameter and 330 mm in length).
3) A sample cut from a glass blow mould manufactured in a local foundry (in Baghdad - Iraq) used in local glass products factory, later named as material No.4.

2.1 Chemical Analysis

The elemental compositions of the tested materials in weight percent are presented in table 1 below using spectrotester manufactured by *AMETEK materials analysis division* – Germany.

2.2 Heat Treatment

In order to have a free residual thermal stresses & homogenized structure after producing the samples via casting, heat treatment (Full annealing or stress relief annealing) is a necessary procedure to be done. The heat treatment cycle for each sample is described below.

1) **EF6 Material**, It is a nickel molybdenum cast iron. It was already heat treated (annealed) as shown in the mould material specification [14].
2) **Material No. 1 & 2**, the microstructure of these cast irons showed graphite flakes embedded in ferrite and pearlite matrix. Pearlite presence in the structure may cause material damage especially when used at relatively high temperature at which the glass blow mould is used. Growth may cause by breakdown of combined carbon (cementite Fe3C) in pearlite. Graphitisation of (1 percent) combined carbon should theoretically be associated with increase in volume of (2.04 percent). Actual growth is always greater than that. Thermal cracks initiation and propagation may occur normally when a casting with pearlite structure is employed at high temperature especially (α to ɣ) transformation temperature range. Growth by pearlite breakdown can be eliminated by the use of ferritic irons. Gray irons can be ferritic structured by annealing. The samples, to be annealed, will be cast with a permissible allowance of (5 mm) left on each side for final machining, and then pack annealed. Pack annealing, using graphite packing, was employed for this

purpose Figure-2. With a (24 h) cycle and a temperature of (850 ºC), full annealing is carried out. In order to avoid residual thermal stresses, the samples are cooled from (850 ºC) down to (200 ºC) with (30 ºC/h) cooling rate and then furnace cooled [15]. Annealing above the critical temperature, in which (α to ɣ) transformation will occur, may accelerate deep oxidation, pack annealing with graphite will inhibit that. Table (2) shows the critical temperature for each test material calculated by using the following formula [13]:

Critical Temperature = 730 + 28(% Si) – 25(% Mn) ……….. (1)

3- Material No.3, Because of its high silicon content (5.117 % Si) with carbon content (2.98 %C), as –cast microstructure, there was flakes of graphite in ferritic matrix. This structure is ordinary ferritic, and in absence of combined carbon, there is no opportunity for growth. It is impossible to produce a casting from foundry without internal stresses. Stress relief heat treatment at (650 ºC) with heating up rate (60 ºC/h) is necessary. Soaking time was (1 h), the cooling down rate (60ºC/h) down to (150 ºC) before removing from the furnace [15].

4- Material No. 4, left without heat treatment, as it is cut from a mould that has already been used in real application.

2.3 Specimens Preparation for optical Microscope Examination

It is necessary to prepare the specimens surface to be flat and free from scratches when viewed by using a microscope. The preparation sequence involves rough grinding of the surface by using coarse emery papers (grade 180). Intermediate and fine grinding are then carried out by using a motor – driven waterproof –emery disc grades (320, 400, 600 and 1000 from coarse to fine). Polishing is carried out with cloth on rotary machine and (3 μm) aluminum oxide paste. After the specimen surface is free from scratch, it is cleaned with a stream of water.

Before etching the specimen, it should be cleaned with grit – free soap solution, and then washed in running water, and then cleaned with methanol for degreasing the surface. When thoroughly cleaned, the specimen is etched by using 2% Nital etching solution. The specimen is then quickly transferred to running water and then dried by immersion it in the alcohol for two minutes [16].

2.4 Microstructural Examination

Optical metallurgical microscope with a digital camera was used to examine the microstructure.

1) EF6 Material

Figure 3, shows the microstructure of material EF6 in three locations (a = by the outside of the mould wall), (b = in the mid thickness of the mould) & (c = by the cavity of the mould).

Fig. 3. Microstructure of material EF6 (Sunquick glass blow mould provided by OMCO – a Belgium company) taken in three locations (a = by the outside of the mould wall), (b = in the mid thickness of the mould) & (c = by the cavity of the mould).

2) Material No. 1, 2 & 3

This examination is carried out within (5 mm) from the as – cast and heat treated surfaces (for both as cast condition and after annealing condition). Materials 1 & 2 as shown in figure (4) are pearlitic and ferritic matrix structure, pearlite has higher hardness than ferrite.

Material No.3 as found in figure (4) showed a fine – grained structure, which means high thermal conductivity. With high silicon content, the structure will be fully ferritic with high and more graphite flakes, which leads to decrease the extent of the cracks propagation, and increase the thermal conductivity. Material No. 3 has an excellent growth resistance for its ferritic as – cast structure. Growth by deep oxidation will be inhibited by high silicon content coupled with copper presence.

3) Material No. 4

Figure 5, shows the microstructure of material No. 4 (two magnifications) which was taken from the inside cavity of the mould. There is a huge amount of phosphorus in this material which produces low melting temperature phosphide eutectic (inclusions).

2.5 Hardness Test

Krautkramer Dyna POCKET hardness measuring instrument is used to carry out hardness test on Brinell hardness scale. Each specimen has been tested for five times and the average is taken. Table 3 shows the Brinell hardness number for all test materials.

Material EF6, The hardness number of this material is in the ferritic matrix range (90 – 160) Brinell and that is clear from the microstructure shown in Figure (3) [2, 3].

Material No. 1 and No. 2, they are pearlitic and ferritic matrix structure, pearlite has higher hardness than ferrite. There is a considerable decrease in hardness after annealing because of microstructure change from pearlite and ferrite to fully ferritic.

Material No. 3, has the highest as cast hardness number among the test materials in this work (328 BHN). High silicon content (5.117 %Si) and presence of copper (1.329 %Cu) cause hardness increase, as shown in Table (3). They are strengthening ferrite and give fine – grain size. High amount of fine –grained structure means high thermal conductivity. With high silicon content, the structure will be fully ferritic with high amount of graphite flakes and that leads to decrease in the cracks propagation, and increase the thermal conductivity [17].

Also Material No. 3 has an excellent growth resistance for its ferritic as – cast structure. Growth by deep oxidation will be inhibited by high silicon content coupled with copper presence.

Hardness value of stress relief casting is higher than before heat treatment because the silicon will be resolved and distributed in ferrite which leads to increase in hardness by strengthening mechanism. The hardness value as well as microstructure will play an important role determining the wear resistance at high temperature.

3. HIGH TEMPERATURE WEAR TESTER

Wear as of main source of glass blow mould damage. It changes the mould feature and fine contours on the cavity surface. In order to study the wear resistance of the mould material, usually wear tester at room temperature is used [1, 4, 13]. When two substances rub each other at relative velocity and axial pressure between them, they get warm. In suitable conditions, the temperature may reach (1300 ºC) when steel – steel specimens rub each other for example, and less than (100ºC) below the melting temperature in nonferrous materials. This phenomenon is employed in friction welding process [18, 19, 20, 21].

In this work, a new rig of pin – on – disc high temperature wear test apparatus is built up depending upon the above phenomenon. This rig is used to examine the gray cast iron specimens supposed to be used as glass blow mould material. High temperature is caused by friction between destination material and an automobile brake pad which has suitable properties to achieve the required temperature.

Using this rig is an attempt to obtain a certain resemblance to working conditions.

3.1 Principle and Theoretical Fundamental

The test is built on the fundamental that, when a controlled axial pressure is applied in perpendicular to the contact surface of two specimens with a relative sliding velocity, heat is generated due to friction force. The produced heat appears as warmth in the contacted substances. The temperature of the two specimens rises. Its amount depends upon many parameters such as:

1) The relative sliding velocity.

2) Axial pressure between the two specimens.

3) Surface roughness.

4) Materials properties (surface hardness, thermal conductivity, etc.).

5) Friction coefficient.

6) Running time.

Temperature can be measured and recorded by using digital thermocouple or an infrared thermocouple.

3.2 The Wear Test Rig Description

A new rig to meet the requirements of wear testing system was designed and fabricated exclusively for this work. The schematic diagram of the testing system is shown in Figure (6).

The unit consists of 1450 rpm, 7.5 Kw, 3 phases electric motor used to rotate the pad at the required velocity through a gearbox. A lathe chuck is mounted on the gearbox output shaft so that the pad holding disc is tightly fixed. The test specimen was fixed on a drill holding spindle mounted into the tailstock. The suitable relative sliding velocity can be chosen by using the speed selector of the lathe's gear box.

Friction pressure can be produced by the movement of the power screw of the tailstock, which then transmits an axial load on the contacted surfaces. This pressure should be controlled to give the required temperature. To rotate the screw, a suspended (1kg) weight moving along a fully threaded bar is used. The adjustment of the torque arm was controlled by adjusting the distance of the weight (on the threaded bar) from the axis of rotation. The applied pressure (i.e. the applied load) is directly proportional to the distance from the axis of rotation. During the test, wear happens both in the specimen and the pad at different amounts which means a loss in thickness and leads to loss or decrease in the pressure magnitude. The suspended 1 Kg weight (as it is always in a horizontal position) will counter balance this and keeps the pressure constant during the test. Temperature is monitored by using a digital thermocouple mounted near the friction surface or, may in future for precise monitoring, an infrared thermometer will be used, focused closely to the friction area itself.

3.3 Test Specimen Preparation.

All wear test specimens of (as cast & heat treated condition) were prepared as shown in figure 7. Test specimen (for materials No. 1, 2 & 3) were cut from the as-cast end of each bar for each material, and the machined to dimensions (in millimeters). Machining parameters were chosen so that a specimen temperature rising is avoided. One specimen from each material was used to fix a thermocouple tip in order to estimate the required temperature by varying the torque arm length (i.e. the friction pressure). This will remain constant for that material at this temperature. ***Sartorius GM612*** digital balance was used to weigh the specimens before and after wear testing.

The friction face was ground, polished and cleaned with solvent before running the first wear. After the specimen was fixed into the rig tailstock chuck, it was cleaned again just before the test to remove grease, dirt, finger prints and any other foreign substance.

3.4 Friction Pad Preparation

An automobile brake pad (12 mm thick) was used as friction material, which rubs the test specimen. After fixing the pad on its base and machining it to its final dimensions shown as in Figure (8), it was ground with emery paper grades (320, 600, and 800) for facing the contact surface. After being cleaned it was fixed in the machine chuck. (D1 = 46 mm), (D2 = 30 mm), (B = 15 mm), (Total Active friction area = 247.078 mm^2) & (A = No contact area).

3.5 Estimating the Test Temperature

First, the rig must be clean and free of grease, oil, dust and any other foreign substance. On other hand, the specimen and pad should be clean, dry and be tightened well before starting the test. The motor is started up and the chuck allowed to rotate reaching the required speed (1000 or 1400 r.p.m) for a while before making a slight contact to avoid any shock. As a result, the specimen will be warm due to friction between the rubbing faces. The temperature rise is monitored on the digital thermocouple; also the time needed to reach the maximum temperature of the cycle is monitored. Increasing torque arm of the suspended load will increase contact pressure and as a result increasing the temperature. When the required temperature (600 or 850ºC) is reached, the pressure is released and the time needed to reach the lowest temperature in the cycle is determined. The test is carried out many times to evaluate all parameters. By using the fully threaded torque arm with two chuck nuts, the suspended weight is mounted in its place to give the desired effect.

3.6 Wear Test Cycle

Each wear test cycle includes contacting (rubbing) the test specimen against the friction pad, and then applying a constant axial load using the power screw of the tailstock, this load produces a constant pressure on the friction pad of (using a torque arm length of Lm = 176 mm, which leads to gain a pressure of P = 3.592 MPa, to reach a wear temperature test of 600 ^{0}C) & (using a torque arm length of Lm = 185 mm, which leads to gain a pressure of P = 3.727 MPa, to reach a wear temperature test of 850 ^{0}C). Friction tests were done on two groups of wear cycle temperatures (600 ^{0}C) & (850 ^{0}C), which corresponds to molten glass temperature. After reaching the desired wear test temperature of (600 or 850 ^{0}C), a friction contact time of 10 seconds is considered and then the pressure is released from test specimen, no contact is performed between the two faces at this phase, and the test specimen is left to air cool and the time needed to reach the lowest cycle temperature of (400 ^{0}C) is determined. After reaching the lowest cycle wear temperature, one wear test cycle is completed. The test specimen is contacted again with the friction pad & friction pressure is reloaded at the same value, and another cycle is started.

3.7 Wear Test

Two group of wear tests have been done at (600 and 850 ^{0}C). Since Glass blow mould surfaces are exposed to damage as a result of wear, growth, thermal fatigue, etc. In order to recognize the performance of gray cast iron employed as a glass blow mould, wear test at high temperature is necessary to obtain true practical and reliable results.

Wear Test at 600 & 800 ^{0}C

The first wear test was carried out at (Maximum Temperature = 600 ºC) and (Minimum Temperature = 400 ºC). Three specimens of each test materials were tested in order to verify the repeatability of the results. The wear in specimens was measured as an accumulated mass loss after each (25 cycles) as a result of the test.

Another set of tests was carried out at (Tmax. = 850 ºC) and (Tmin. = 400 ºC), three specimens of each test materials were tested in order to verify the repeatability of the results. The wear in specimens was measured by accumulated mass loss after each (10 cycles), as shown in table 4.

4. RESULTS OF WEAR TESTS

The results of wear in three specimens of each test material is measured by accumulated mass loss using a digital balance, the weights of these specimens were weighed before and after running the wear test as a function of number of cycles.

Weight Loss of each specimen (as function of number of cycle) = Weight of specimen before running the wear test – Weight of specimen after running the wear test.

Average weight loss of each material = (Total weight loss of 3 specimens of the same material) / 3

4.1 Weight loss at 600 ^{0}C Wear Test cycles (Before annealing)

The average weight loss in grams results for each test material is shown in figure (9) for as – cast materials (before annealing) in relation to EF6 at 600 ^{0}C wear test.

As evident from Figure (9), EF6 material has lower weight loss than test material No.1 and material No.2 for the same number of cycles all over the test, in spite of their high hardness numbers as compared with EF6, as shown in table (3) before annealing. It can be concluded that hardness is not the unique criterion for wear resistance at high temperature. Material No.3 has the highest hardness number among the test materials, as shown in table (3), and it provides the lowest weight loss among test materials even than that of EF6.

4.2 Weight loss at 600 ^{0}C Wear Test cycles (After Full annealing)

Figure (10) shows that full annealed material No.1 gives the highest weight loss among the test materials followed by full annealed material No.2 and then EF6 material. Stress relief annealed material No.3 has the lowest weight loss per cycle among all test materials due to its chemical composition and microstructure, i.e. high amount of graphite flakes with silicon - strengthened ferrite as shown in Figure (5).

As it can be seen from Figure (9) and Figure (10) for material No.1 & material No.2, that as – cast materials have better wear resistance than heat treated (annealed). Pearlite presence in as

– cast microstructure will improve wear resistance. Pearlite breakdown (high temperature growth) provides further number of graphite flakes in the surface microstructure. Although increasing graphite content in the microstructure will improve thermal conductivity by providing heat dissipation paths, it also increases weight loss. Extra soft graphite flakes play a negative role by increasing surface roughness which leads to an increase in weight loss.

From Figure (4) for material No.3, it is obvious that there is no change in microstructure between the as – cast and after stress relief annealing. The high hardness values of annealed specimens can be attributed to dissolution and distribution of silicon in ferrite which will be strengthened. This hardness increase has major effect on wear characteristics and gives the lower weight loss.

4.3 Weight loss at 850 ^{0}C Wear Test cycles (Before annealing)

The average weight loss in grams results for each test material is shown in figure (11) for as – cast materials (before annealing) in relation to EF6 at 850 ^{0}C wear test. As evident from Figure (11), EF6 material has lower weight loss than test material No.1 and material No.2 for the same number of cycles all over the test, in spite of their highest hardness number as compared with EF6, as shown in table (3), before annealing.

Material No.3 has the highest hardness number among the test materials, as shown in table (3), and it provides the lowest weight loss among test materials.

Figure (11) shows that as cast material No.2 has the greatest weight loss of the test materials followed by as cast material No.1 and then EF6 material. As – cast material No.3 has the lowest weight loss per cycle of all test materials for its chemical composition and microstructure i.e. high amount of graphite flakes with silicon - strengthened ferrite as shown in Figure (5).

4.4 Weight loss at 850 ^{0}C Wear Test cycles (After Full annealing)

Figure (12) shows that full annealed material No.2 gives the highest weight loss among the test materials followed by full annealed material No.1 and then EF6 material. Stress relief annealed material No.3 still has the lowest weight loss per cycle among all test materials due to its chemical composition and microstructure, i.e. high amount of graphite flakes with silicon - strengthened ferrite as shown in Figure (5).

As shown in Figure (11) and Figure (12) for material No.1 & material No.2, the as – cast materials with pearlite and ferrite microstructure have the greater weight loss than annealed materials. This is an evidence of different behavior of that at (600 ºC).

As shown in Table (2), material No.1 and material No.2 were tested in the (α to ɣ transformation temperature range) which led to growth by both pearlite break down and matrix oxidation. Growth will cause crack initiation and propagation at a high rate and with graphite flakes small parts from the surface will be detached.

Material No.3 as shown in Table No. (2) was tested at a temperature below its critical temperature. As shown in Figure (5), the microstructure before and after stress relief annealing is ferritic. In the absence of cementite and pearlite, there is no growth probably by break down of combined carbon. High silicon with copper content inhibits matrix oxidation and growth as a result.

4.5 Weight loss at 600 & 850 ^{0}C Wear Test cycles (Before annealing) for Material No. 4

This material provides an excellent wear resistance when tested at (600 ºC), as shown in Figure (13), as a result of high hardness structure components.

When it was tested at (850 ºC), it showed the worst wear resistance of the test materials, Figure (14). High amount of phosphide eutectic in structure, melted at temperature near (900 ºC) [5].

The phosphide eutectic melt by hot spots produces high surface roughness and that caused high weight loss. High amount of pearlite in structure, and low silicon content led to surface damage as a result of growth both by pearlite or combined carbon break down and matrix deep oxidation.

5. CONCLUSIONS

The main conclusions drawn from the present work can be summarized as follows:

1) Material No. 3 showed the best wear resistance (minimum average weight loss) among all other materials in both as-cast & heat treated condition.
2) The wear tests show that hardness is not the only criterion for resistance to abrasive wear especially at high temperature.
3) Pearlitic structure material possesses higher hardness at room temperature than ferritic for the same chemical composition and it demonstrates better wear resistance than ferritic at high temperature before (α to ɣ transformation) i.e. up to approximately 600 ºC as well as at room temperature.
4) In the (α to ɣ transformation) temperature range, ferritic gray cast iron has higher wear resistant than pearlitic due to its resistance to growth by pearlite and free cementite break down and deep oxidation.
5) Increasing silicon content in presence of copper, while it gives as cast ferritic structure, it also increases the hardness, because it is dissolved in ferrite and strengthened it. The short heat treatment cycle of this material coupled with its good wear resistance at high temperature make it relatively cheap.

6) Stress relief annealing of high silicon gray cast iron while it is done at low temperature and needs short time to achieve that, it will increase hardness because silicon is dissolved and distributed into ferrite, or at least safe the same hardness number.
7) Some gray cast iron (e.g. pearlite structure, mottled structure and white cast iron) has an excellent wear resistance at low temperature, but at elevated temperature, especially at (α to ɣ transformation) temperature range, it is weak. Therefore, wear test at room temperature for gray cast iron will never give a good indication of material wear resistance if the material is designed to be used near the critical temperature.
8) Wear rate for all tested specimens were approximately constant, which means no sudden increase in wear values occurred, and it shows that the suggested wear testing procedure by the developed rig is in the acceptance level of reliability.

REFERENCES

1) Johnson O. et al "Effect of silicon additions on the wear properties of gray cast iron" JMMCE, Vol. 1, No. 2, March 2013.
2) H. T. Angus, "Cast Iron: Physical and Engineering properties", Butterworths, second edition reprinted, 1978.
3) Elliott, R., Cast Iron Technology, Butterworth-Heinemann, Great Britain, 1998.
4) Glass Mold Temperature, Application Notes AN103, Part No. 010202 Rev. B, IRCON, INC. 1998.
5) R. A. Higgins, Materials for the Engineering Technician, Edward Arnold, London, 1988.
6) Raymond A. Higgins, Engineering Metallurgy, part 1 Applied physical metallurgy, The English Universities Press LTD, Fourth edition 1973.
7) John R. Brown, Foseco Ferrous Foundryman's Handbook, Butterworth-Heinemann, Foseco, International Ltd, Oxford, 2000.
8) Junichiro Yamabe, Masami Takagi and Toshiharu Matsui, Development of Disc Brake Rotors for Heavy – and Medium – Duty Trucks with High Thermal Fatigue Strength, Technical papers, Technical Review, No. 15, 2003.
9) G. Cueva, A. Sinatora, W. L. Guesser and A. P. Tschiptschin, Case Study, Wear Resistance of Cast Irons Used in Brake Disc Rotors, Wear 255(2003) 1256 – 1260.
10) Sugwon Kim, S.L. Cockcroft, A.M. Omran, Honam Hwang, Mechanical, wear and heat exposure properties of compacted graphite cast iron at elevated temperatures, Journal of Alloys and Compounds, Volume 487, Issues 1–2, 13 November 2009, Pages 253–257.

11) M. H. Cho, S. J. Kim, R. H. Basch, J. W. Fash and H. Jang, Tribological study of gray cast iron with automotive brake linings: The effect of rotor microstructure, Tribology International, Volume 36, Issue 7, July 2003, Pages 537-545.

12) Peter J. Blau, Brian C. Jolly, Wear of truck brake lining materials using three different test methods, Wear, Volume 259, Issues 7–12, July–August 2005, Pages 1022–1030.

13) Glass Packaging Institute, Educational materials, 2005.

14) OMCO, Mould data sheet, I – 6 (June 1975).

15) Heat Treating, ASM Handbook, Volume 4, 2004.

16) Metallography and Microstructures, ASM Handbook, Volume 9, 2004.

17) M Yousuf Anwar (A study on thermal cracking of cast iron used in glass blow moulds), Pakistan Eng. Congreve 70th annual session proceedings, Paper No. 677, P 415 – 422, 2012.

18) R. F. Tylecote, The solid phase welding of metals "Friction Welding", pp. 226-257, Arnold 1968.

19) F. D. Duffin and A. S. Bahrani, "The mechanics of friction welding mild steel", Metal Construction, Vol. 8, No. 6, 1976.

20) Agunsoye J.O, et al (Effect of H.t on the abrasive wear of high Cr cast iron) trib. In industry. Vol. 34, No. 2 (2012) 82-91.

21) Kapil Chawla, et al (Investigation of tribological behavior of gray cast iron in pin on disk addaratus), IOSR-JMCE, vol.9, issue 4 (Nov. Dec. 2013), 18-22.

Table (1): chemical composition (Wt%) of used materials.

Sample No.	C%	Si%	Mn%	P%	S%	Ni%	Mo%	Cr%	V%	Cu%	Fe%
EF6 Material	3.5	1.95	0.77	0.1	0.066	0.37	0.44	---	---	---	Bal.
Material No. 1	3.61	2.03	0.74	0.09	0.067	0.063	0.0052	0.021	0.0041	---	Bal.
Material No. 2	3.15	2.25	0.671	0.108	0.062	0.069	0.006	0.021	0.0052	---	Bal.
Material No. 3	2.98	5.117	0.355	0.11	0.057	0.071	0.0056	0.022	0.0034	1.329	Bal.
Material No. 4	2.91	1.33	0.401	0.454	0.16	---	0.0049	0.217	---	---	Bal.

Table (2): The critical temperature for tested materials

Sample No.	Si%	Mn%	Critical Temperature °C (calculated according to equation No. 1
EF6 Material	1.95	0.77	765.35
Material No. 1	2.03	0.74	765.35
Material No. 2	2.25	0.671	776.22
Material No. 3	5.117	0.355	864.4
Material No. 4	1.33	0.401	757.2

Table (3): Hardness average number before and after annealing.

Sample No.	Average Brinell Hardness Number		Heat Treatment
	As cast – Before annealing	After annealing	
EF6 Material	1	135	As received
Material No. 1	260	145	Annealing
Material No. 2	240	141	Annealing
Material No. 3	319	328	Stress Relief
Material No. 4	244	-----	As received

Table (4): Wear Test Parameters of 600 & 850 °C cycle

Condition	Wear Test at 600 ^{0}C	Wear Test at 850 ^{0}C
Maximum Temperature (ºC)	**600 ± 10**	**850 ± 10**
Minimum Temperature (ºC)	**400 ± 10**	**400 ± 10**
Time Needed to Reach Maximum Temperature (Sec)	**50**	**110**
Friction Contact time at 600 oC (Sec.)	**10**	**10**
Time Needed to Reach Minimum Temperature (Sec)	**85**	**175**
N (r.p.m)	**1000**	**1400**
Torque arm length Lm (mm)	**176**	**185**
Friction Pressure (MPa)	**3.592**	**3.727**
Axial Load (N)	**887.5**	**920.85**
Friction Mean Linear Velocity (mm/s)	**1.9897**	**2.7855**

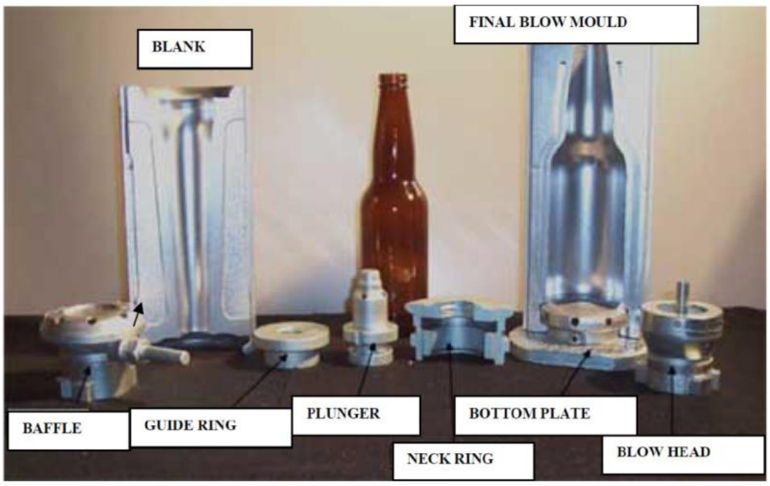

Figure (1): Glass blow mould parts [13].

Figure (2): specimens packing sealed steel box.

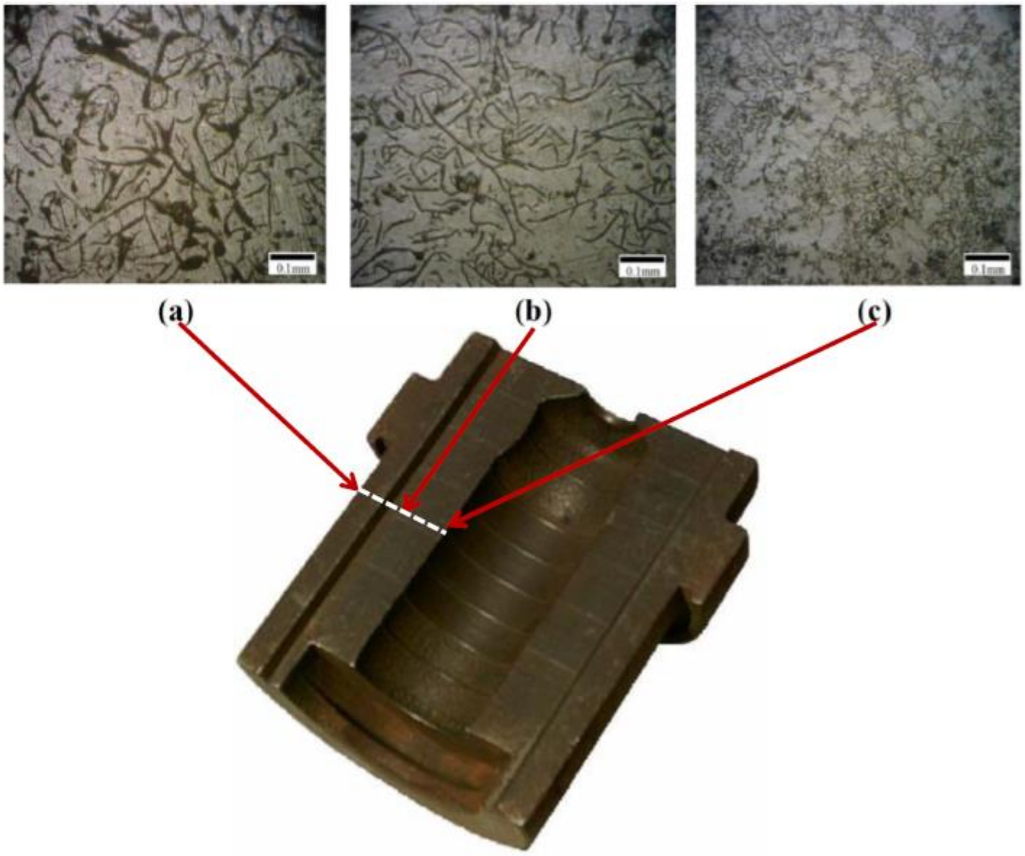

Figure (3): Microstructure of material EF6 (Sun quick glass blow mould provided by OMCO – a Belgium company) taken in three locations (a = by the outside of the mould wall), (b = in the mid thickness of the mould) & (c = by the cavity of the mould).

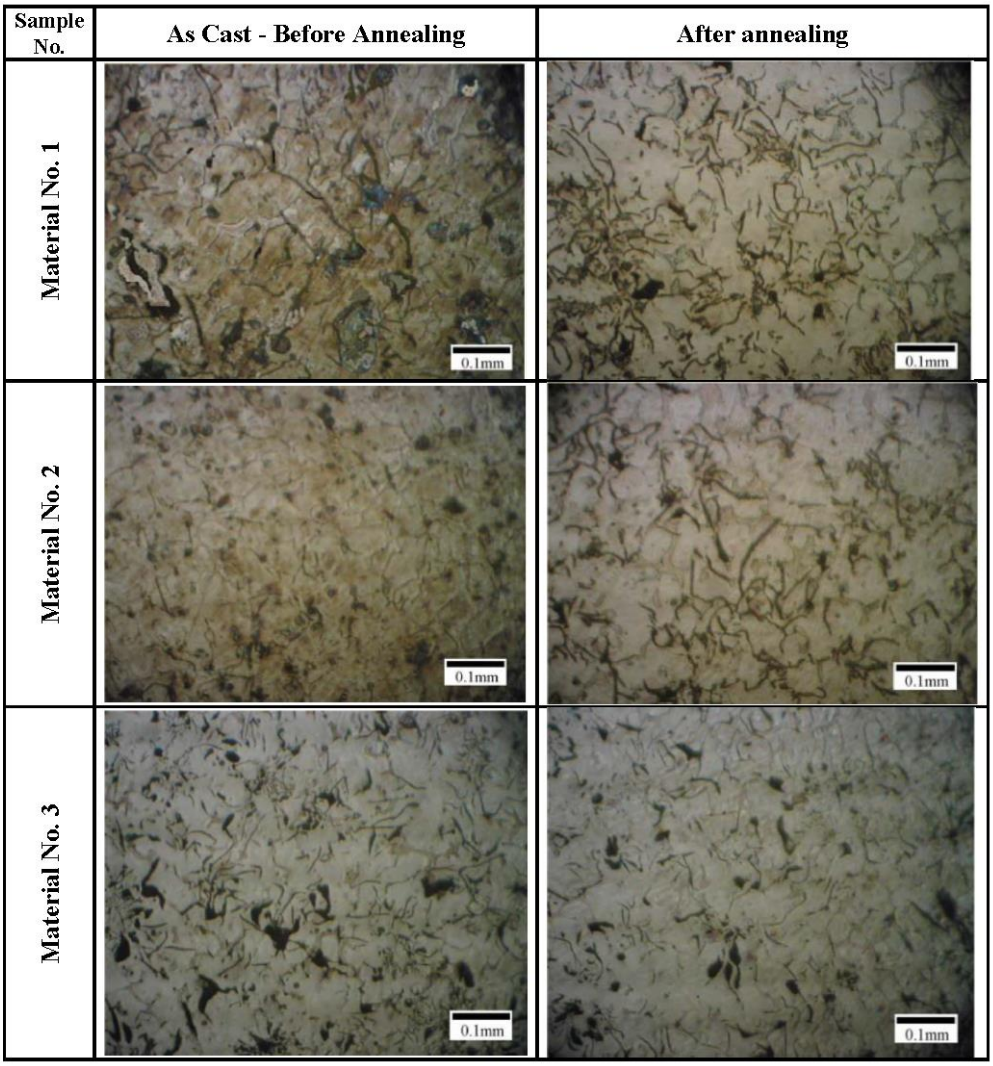

Figure (4): Microstructure of material No. 1, 2, & 3 before and after anneal.

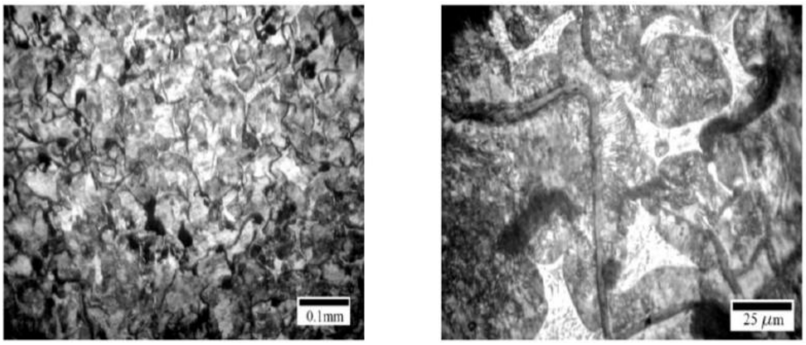

Figure (5): Microstructure of material no. 4 (as cast condition without heat treatment).

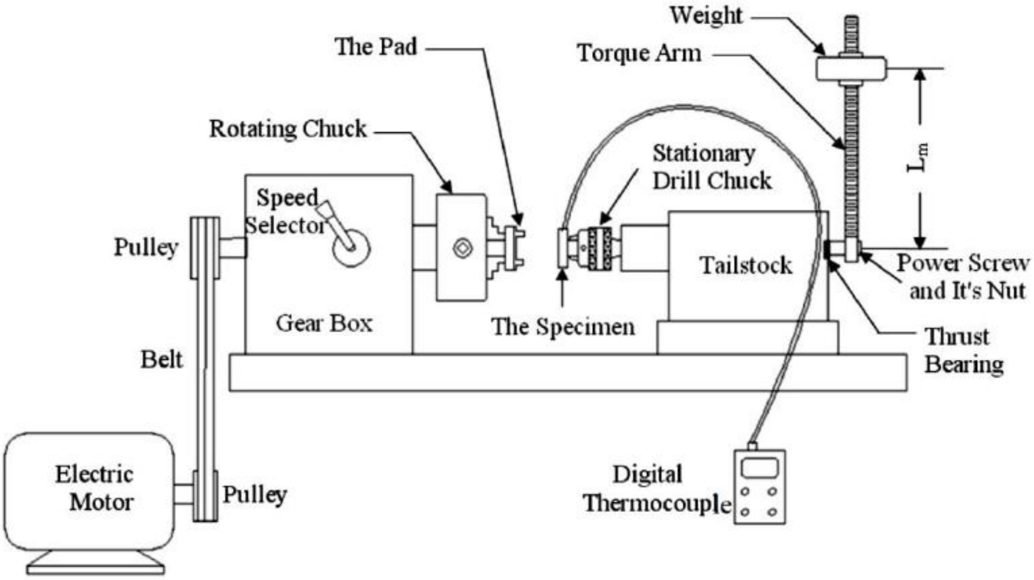

Fig. 6. Schematic diagram of the wear tester

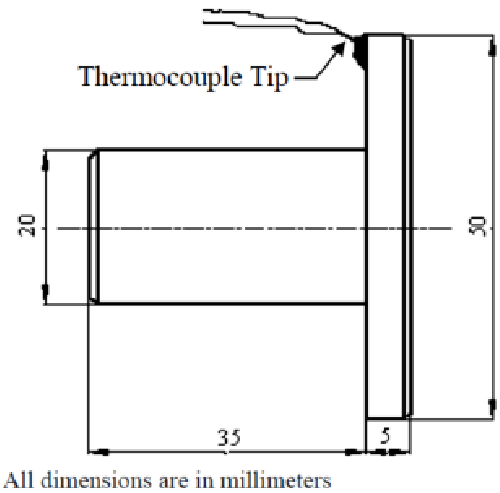

Figure (7): wear test specimens (for both as cast & heat treated condition).

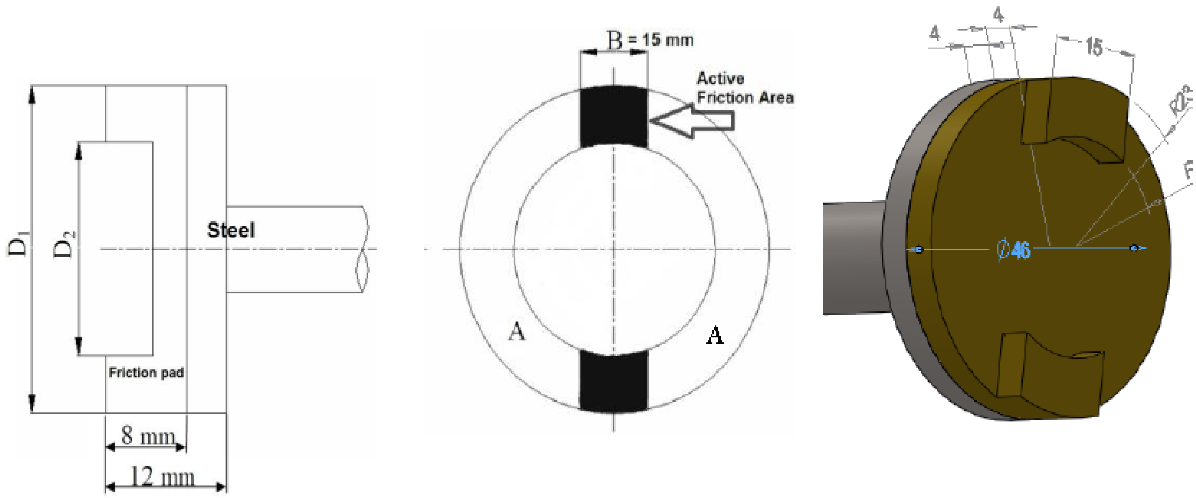

Fig. 8. The friction material Pad

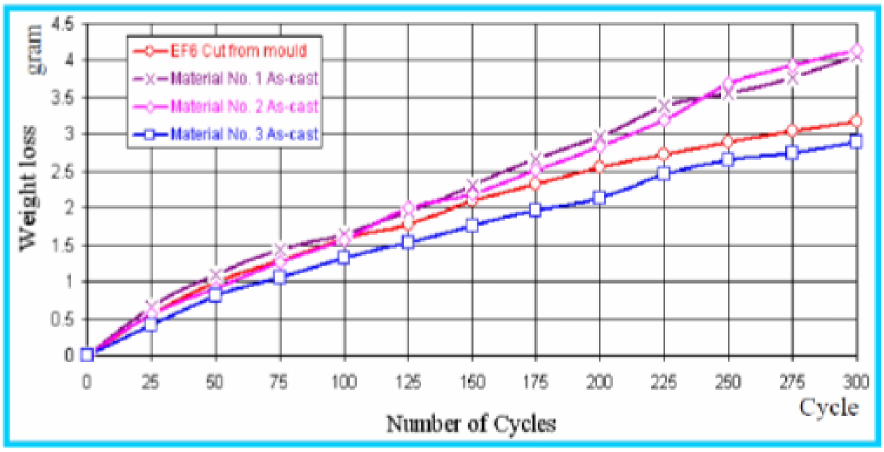

Figure (9): Average Weight loss (gram) as a function of number of cycles for as-cast materials (Before annealing) tested at 600ºC.

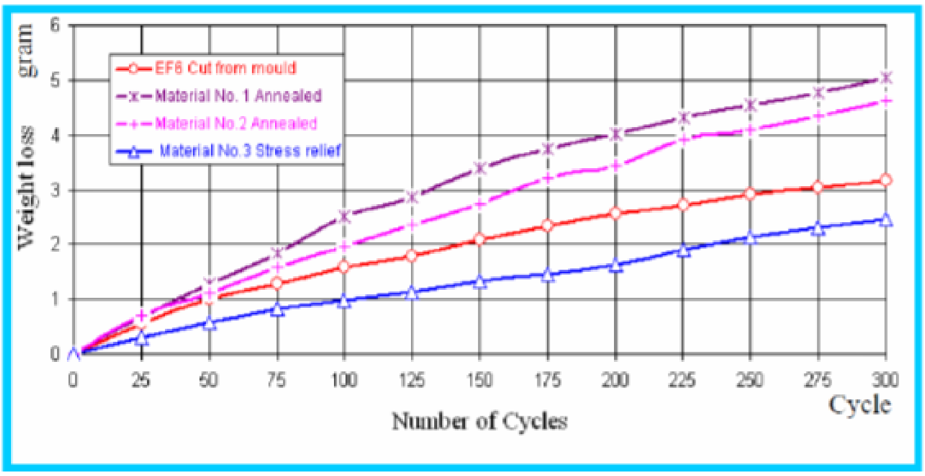

Figure (10): Average Weight loss (gram) as a function of number of cycles for heat treated materials (After full annealing) tested at 600ºC.

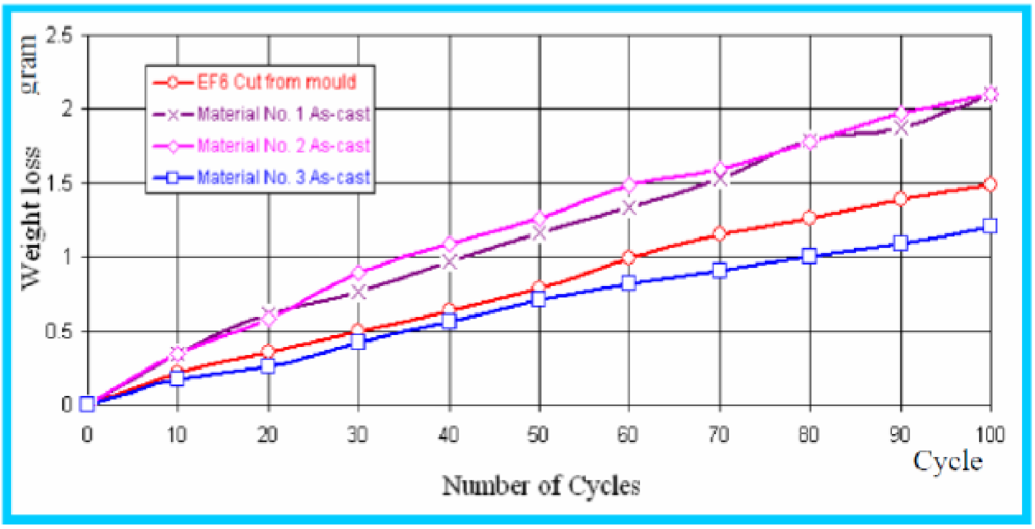

Figure (11): Average Weight loss (gram) as a function of number of cycles for as-cast materials (Before annealing) tested at 850ºC.

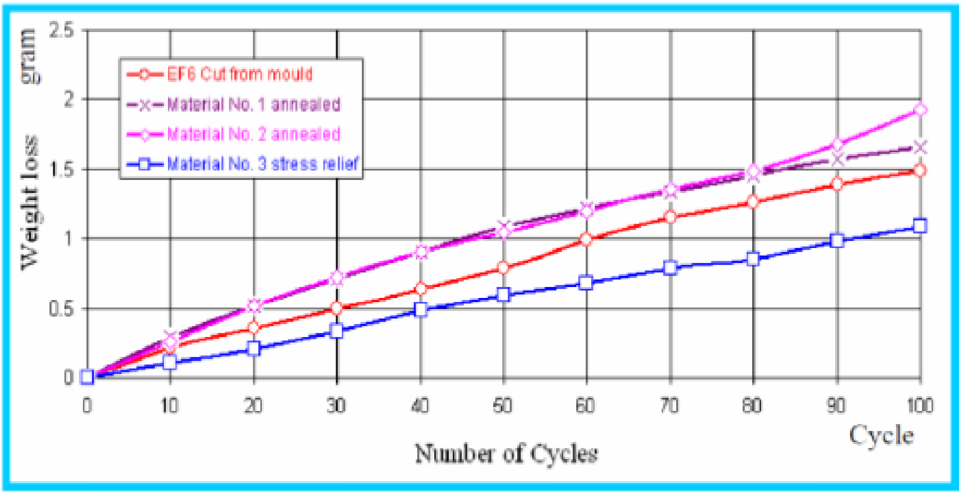

Figure (12): Average Weight loss (gram) as a function of number of cycles for heat treated materials (After full annealing) tested at 850ºC.

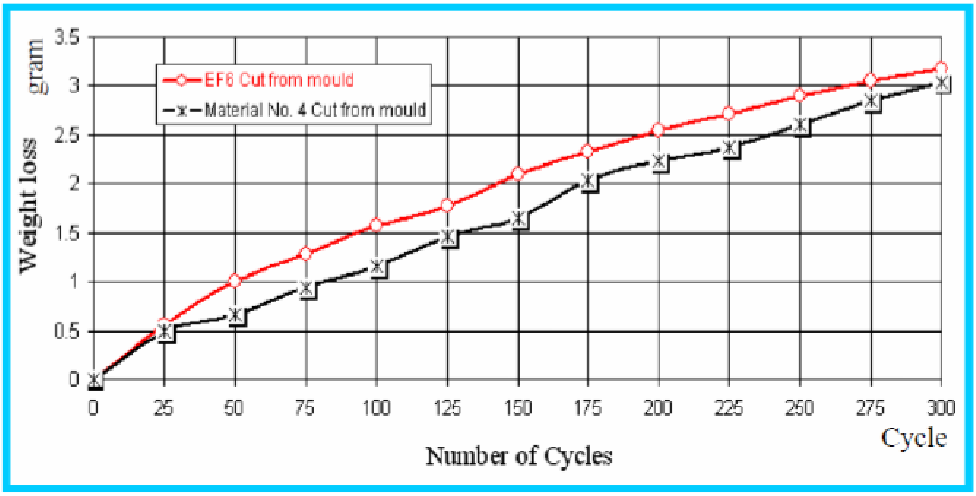

Figure (13): Average Weight loss of material No. 4 compared with EF6 material as a function of number of cycles for as-cast condition tested at 600ºC.

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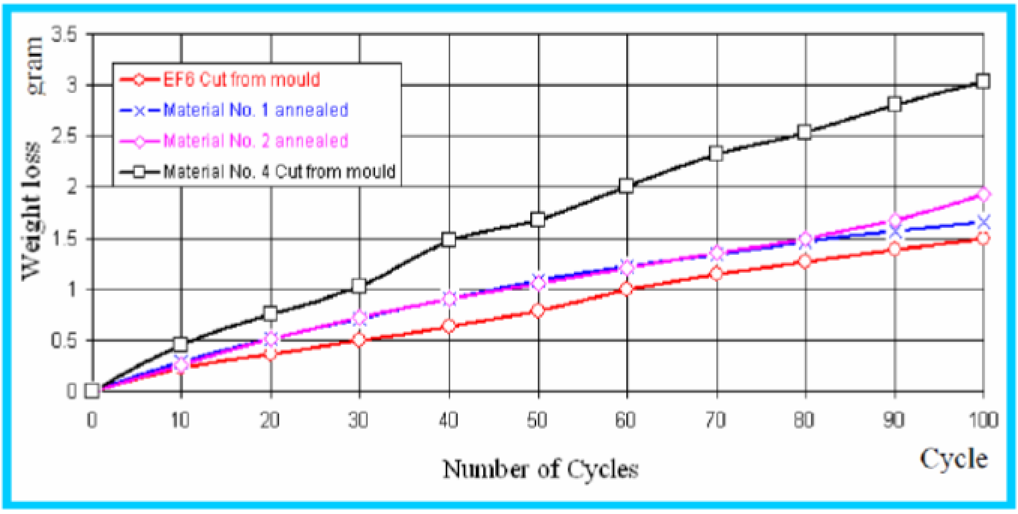

Figure (14): Average Weight loss of material No. 4 (as-cast condition) compared with other (heat treated condition) materials as a function of number of cycles tested at 850ºC.

مقاومة البلى لأنواع مختلفة من حديد الصب المستخدم في صناعة قوالب الزجاج

كاظم مجبل مشلوش

مدرس

الكلية التقنية الهندسية – بغداد

الخلاصة

ان الغاية من هذا البحث هي دراسة خواص البلى لانواع مختلفة من حديد الصب (حديد الزهر) التي يمكن استخدامها في صناعة قوالب النفخ للعبوات الزجاجية.

تم تصميم وتطوير منظومة خاصة لاجراء اختبارات البلى. تم سباكة ثلاثة انواع من حديد الصب ذات التركيب الكيماوي المختلف واجراء التعامل الحراري عليها بعد السباكة, اضافة الى اخذ عينات من قوالب حقيقية تم استخدامها سابقاً في صناعة العبوات الزجاجية.

تم اجراء تجارب البلى باخذ نماذج من المعادن المعده للاختبار عن طريق الاحتكاك بعينة من المادة الاحتكاكية المستخدمة في موقفات السيارة, تحت ظروف تجربة مختلفة من سرعة الانزلاق, ضغط الاحتكاك, وزمن التلامس اثناء الاحتكاك.

تم حساب الوزن المفقود للعينة بعد التجربة عند درجتي حرارة 600 و 800 م^0.

اظهر حديد الصب الذي يحتوي على (2.98% كاربون, 5.177% سليكون, 1.39 % نحاس) اعلى صلادة بعد السباكة مباشرة وبعد التعامل الحراري كذلك مقارنة بالمعادن الاخرى, اضافة الى امتلاكه اعلى مقاومة بلى بعد التعامل الحراري (تلدين ازالة الاجهاد).

اظهرت النتائج كذلك ان بعض السبائك ابدت مقاومة بلى عالية عند درجات الحرارة (لحد 600 م^0) ولكنها انخفضت عند درات حرارة (800 م^0). كما بينت تلك النتائج ان الصلادة هي ليست العامل الوحيد الذي يسيطر على مقاومة البلى عند درجات الحرارة العالية.