Friction and Wear behaviour of NiCr/ SiC based composites

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Abstract: *Ni based Metal matrix composites (MMCs) have attained growing importance in industries and advanced technologies, for tribological applications because of their potential uses in the automobile, aerospace especially for applications to sliding parts.In this project 95 % of Nickel chromium (NiCr) based composite containing 5 % Silicon carbide(SiC) is reinforced in different percentages prepared by powder metallurgy method. In powder metallurgy we used ball milling method for proper mixing of combined powders followed by compaction and sintering. These samples are compacted at 3 different pressures for each sample 60 KN,70 KN,80KN respectively. The samples after compaction are sintered using different times 60min,90min,120min for constant temperature 1000^0c.The prepared samples were examined for micro structural and mechanical properties like hardness and compressive strengths which are important properties for materials.For tribological studies the friction and wear behavior is examined by using pin on disk tribological set up. This showed that tribological properties got improved by increasing the loads and sintering time of NiCr and SiC composites at the temperature of 1000 ^{0}c. The best comprehensive properties of tribology are being obtained when the sample prepared by load of 80KN and sintering time of 120 min which exhibited wear rate(1.1 x $10^{-5}$$mm^3$/Nm) and lowest friction coefficient (0.56).*

Keywords: **Metal matrix composites ,Wear rate ,Friction Coefficient**

1.INTRODUCTION

In the recent trend ,the Nickel based reinforced composites had been the best for the industrial applications namely aerospace, marine and automobile and many more.Various techniques had implemented to improve the microstructure and to obtain desired mechanical properties.The overall aim of the reinforced composites is to be the better performed engineering materials.The reinforced composites which in progress improves the quality of the material and also progress the better international market share.The market demand for high performance ,stiffness and strength of the materials is increasing rapidly with the optimized cost and weight of the materials. The function of the composites is to enhance work ability and to improve the physical and mechanical properties .It possess hight strength ,good ductility and high strength to weight ratio, low thermal expansion coefficient .The composite possess excellent wear resistance ,better fatigue strength and high temperature creep resistance.The composites will be either in the form of metal,ceramic ,plastic and the reinforcement will be in the form of fibre or particles.[1-4].

The reinforcement can be used in the form of metals,carbides and oxides. At present many reasearches are done to improve the metal matrix composties(MMC).Many methods for developing the metal matrix composites are done namely Metal injection moldings ,friction stir process, Liquid fabrication method, solid state fabrication method,mechanical alloying. The metal matix can be reinforced by numerous reinforcements with variety of types like graphite, SiC, Al2O3, TiO, MgO, SiO2, B4C, TiC, WC, h-BN and C in the form of particulates, whiskery structures or fibrous matter.[5-6]

Nickel alloy has wider applications in aerospace ,marine and turbine engines for their excellent tribological and mechanical properties at elevated temperatures.The nickel alloy has its higher density and creep resistance limit for their future applications. However ther nickel based composites can reduce density and meanwhile improve mechanical properties and high temperature of nickel matrix which makes to have the wider applications int market for pumps, valves, marine and aerospace industries and the overcome the problems of the nickel based composites and become cost effective.[7]

R.Tiwari also investigasted that the effect of chromium addition also increased the yield strength and the hardness of the Ni-Al alloys[8]. From the recent trend, SiC has been used as new reinforcing material and is successful in improving the tensile properties. SiC posses good electrical conductivity, thermal , chemical stability,high mechanical strength and low friction properties.It is observed that the addition of SiC can strengthen a metal matrix and improves many more mechanical properties. The grain structure of the MMCs also could be improved by adding SiC[9-10]. The author investigated that the combinations of Ni(1-3.5%)-SiC at different weights and loads found as the ideal combination for the strength and plastic properties[12].The combinations are mainly done by sintering techniques which improved hardness and decreased the density of the composite.It has found that the wear rate of the combinations decrease with the increase in the temperatures[6].The microstructure has become finer with the combinations of Ni-SiC than before. The tensile strength and the hardness got increased by these combinations(13-15).Xinmin investigates pin on disc tribological studies for good and accurate results for wear rate and friction coefficients for standard steel gear materials.[16].

In this research ,several NiCr-SiC composite samples were prepared by Ball milling method and with UTM(Ultra sonic testing machine).Then followed by different loads and sintering temperatures to eludicate the changes in the microstructure and mechanical properties.One major goal of this research is to investigate the strenghteing capabilities if SiC for NiCr metal for improving the the strength and hardness.To investigate the best wear rate and friction coefficients of the samples on Pin on disc machine.To obtain redefined grain structures .

2 .1 Material and Methods

2.1.1 Preparation of Ni- Based composites

The composition of 95% Ni-Cr and 5% of SiC is taken for the preparation of sample. These powders were mixed by Ball milling method.The powders taken according to their respective weights were blended using a blender for uniform distribution of particles i.e 475 grams of Ni-Cr and 25 grams of SiC was blended in a blender. The specimen was made using a die made of EN32 with diameter 12mm. For making of each specimen, 8 gm of blended powder mixture was taken. The powder was weighted using an electronic balance with least count of 1gm. The powders were handelled very carefully to avoid

oxidation and reaction with atmospheric gases. Acetone was used for cleaning of die and zinc stearate was used for lubrication purpose of die. The powder was compacted in the die using 'UNIVERSAL TESTING MACHINE'with maximum capacity of 4000tons ,by applying appropriate loads. During the compaction process,the punch speed was carefully controlled since high force will produce a very less density of specimen so the life of the specimen is less .An ejector was also used for removal of specimen from the die..About 9 samples were prepared by 3 different loads each of 60KN,70KN,80KN by the mixture of NiCr and SiC composites. After compaction Green compacts were rolled in nylon tape to prevent oxidation.



Fig 2.1 Green compacts

Flowchart representing process methodology:

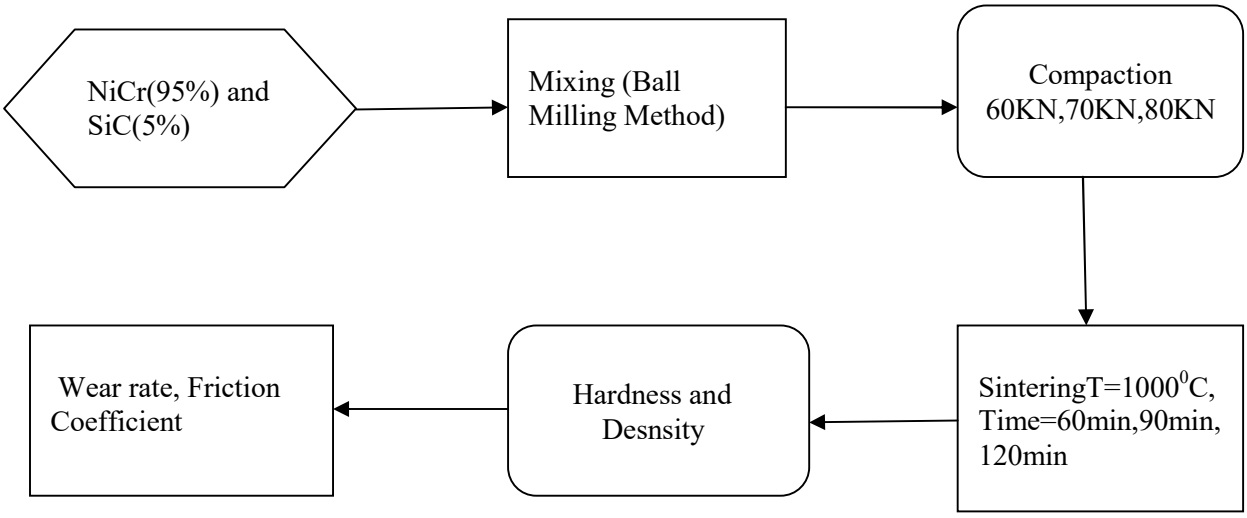

Fig 2.2 Experimental process methodology

2.1.2 SEM Analysis

In the below SEM analysis we can see that Ni-Cr powder mixture consists of 8.57% of oxygen ,2.57%of silicon and 75.69%of Ni. Very low percentage of impurities where found in the powder. similarly in the SEM analysis of SiC it was observed that no impurities were present in the powder. There was no oxygen content in the powder. As a result oxidization of Si and C to SiO2 and CaCO3 could be prevented.

Thus during the making of specimen, the properties of Si and C could be retained in the composite material and prevent any reaction taking place between the powders because of oxidization.(17)

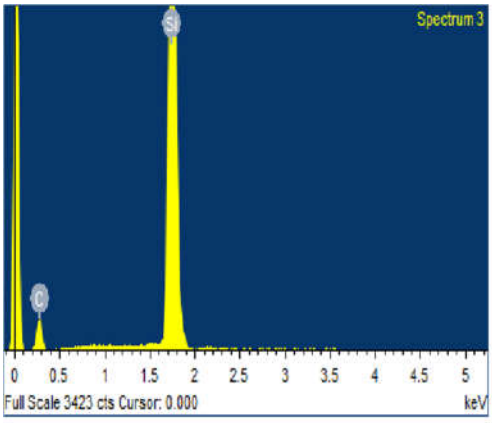

Fig 2.3 SEM micrograph of Sic powder mixture

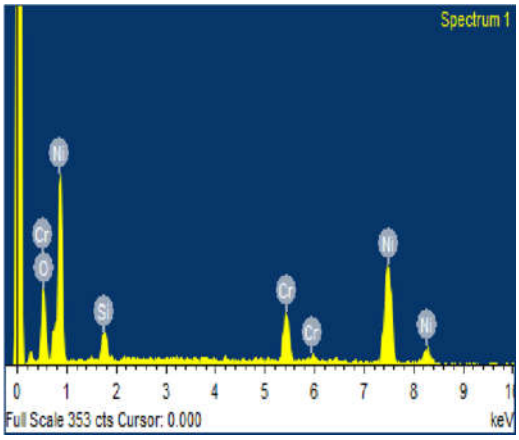

Fig 2.4 SEM micrograph of Nicr powder mixture

2.1.3 Sintering

The prepared green compact samples did not have enough strength, to improve the strength of the green sample go for sintering process. The compacted green samples where sintered in tubular furnace in presence of vacuum..In Sintering process green compacts which was prepared by Compaction was heated at a temperature of 1000°C employed. The specimen were soaked for a time of 60min,90min and 120minrespectively. A pressure of -0.95 bar is created in the tubular furnace to prevent oxidation of specimens.After completion of sintering process samples were cooled in the furnace itself to the room temperature, then the samples taken out from the furnace and the mechanical tests for characterization.A chiller was used for circulation of cold water through vacuum O rings.

2.1.4 Wear rate measurement

Wear rate of the 9 specimens were conducted on Pin on disc setup of Magnum model-TE-165.The specimens were cleaned with acetone before wear tests. A 20 N load is applied at the back holder of the machine and the sample is adjusted at the pin. The wear and tear of the machine is set to zero and the set time of 15 min of machine set for experiment. The disc rotates at the speed of 1000rpm. The disc starts to rotate when the start button is pressed until the time which is already set for the machine.After rotated for the required time on the pin on disc machine the sample gets wear and it is removed from the pin and tested for further purposes. The tests are repeated 3 times and the average value is taken.The same processes is carried out for the same 9 samples respectively.

Table 2.1 Different loads used for compaction and sintering temperature and soaking time at constant temperature of 1000 ^{0}c is given below.

Samples	Load (KN)	Sintering time (min)
1	60	60
2	60	90
3	60	120
4	70	60
5	70	90
6	70	120
7	80	60
8	80	90
9	80	120

Table 2.2 Tribological test parameters used in this experiment

Tribological parameters	Experimental conditions
Applied load (N)	20
Rotational speed(rpm)	1000
Sliding speed(m/s)	10
Specimen diameter (mm)	8
Pin diameter (mm)	8
Pin length (mm)	30
Temp(^{0}C)	25±2
Humidity(%)	67±2

3 Results and Discussions

3.1 Microstructure and Mechanical properties of Ni-Based composites

Metallographic studies of the composite specimen Ni-Cr/SiC produced and specimen made up of Ni – Cr after sintering was carried out .From the above microstructures of the specimen we can observe that SiC was uniformly distributed in Ni-Cr/SiC composite material because of ball milling used for mixing of the powders. Uniform distribution of the elements results in the specimen exhibiting better properties than that of specimen produced by non-uniform distribution of the elements.

Microstructure obtained of the composites are relatively dense. It is observed two different phases in the microstructures Gray phase ,deep gray phase. Gray phase is rich in NiCr and the deep gray phase is rich in SiC composites. The incorporation of SiC composite on to the NiCr resulted in decrease in the density(13). This shows that with the increasing compaction pressure and increasing sintering time as considered from table 2.1 ,the microstructures of the resulting samples became very dense and the poristy

became less.The microstructure became more denser because the bonding between the molecules become stronger and it is seen in the microstuructures as the compaction pressure and sintering time increases.

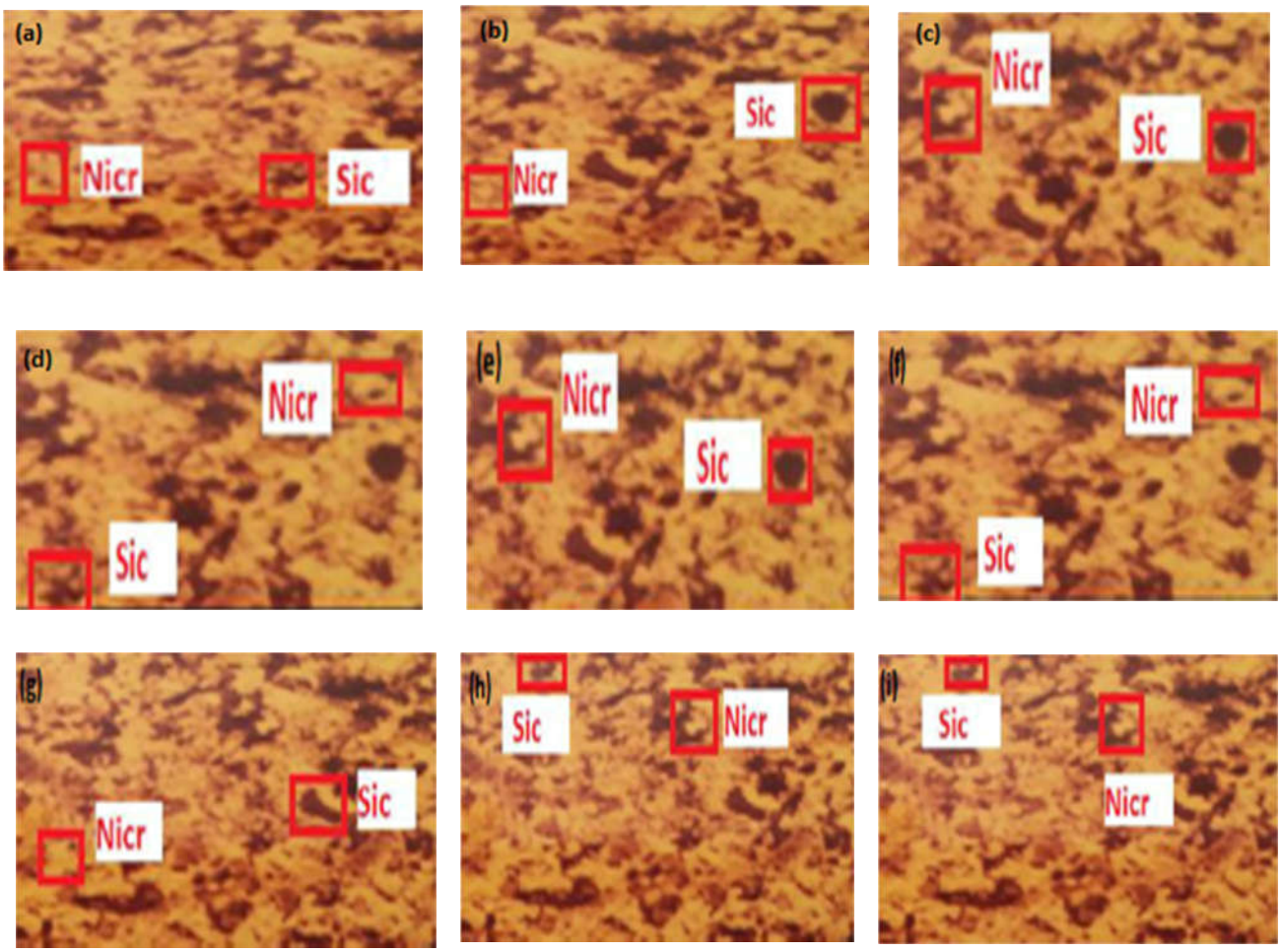

Fig 3.1 Microstructures of specimens tested after sintering (a) Microstructure of 60KN load and 60min sintering time ; (b) Microstructure of 60KN load and 90 min sintering time ; (c) Microstructure of 60KN load and 120 min sintering time; (d) Microstructure of 70KN load and 60 min sintering time ; (e) Microstructure of 70 KN load and 90 min sintering time ; (f) Microstructure of 70 KN load and 120 minisintering time; (g) Microstructure of 80KN load and 60 min sintering time; (h) Microstructure of 80KN load and 90 min sintering time ;(i) Microstructure of 80KN load and 120 min sintering time.

3.2 Measurement of hardness and density

Hardness is considered as the key factors of the wear tests. Greater the hardness the lesser will be the wear rate of the material. There are different methods to find the hardness but finally they give the same results .Ductility of the specimen is found by measurement of the hardness hardness . Brinell scale is used for the measurement of the hardness.This tests uses 10mm(0.39in) dia steel bar as indentor with 3000kgf force.For harder material tungsten carbide ball is used instead of steel bar as an indentor. The test method used is ASTM E 10-2018 .The ball diameter used is 2.5mm and the load used is 15.625 kg.The Brinell hardness teast method is used to determine the hardness of the specimens.The specimens were polished using grades of emery sheet before hardness testing

process.The hardness were measured at three different points and average of the hardness was taken. Densities of the specimens are measure using the Archimedes method.

Table 3.1 Results of hardness and densities

Samples	Hardness	Desnities (g/cm^3)
1	30.3	5.521
2	31.3	4.4991
3	32.7	4.957
4	31.2	5.225
5	32.5	5.125
6	33.7	5.071
7	32.7	5.202
8	33.4	5.019
9	34.5	4.852

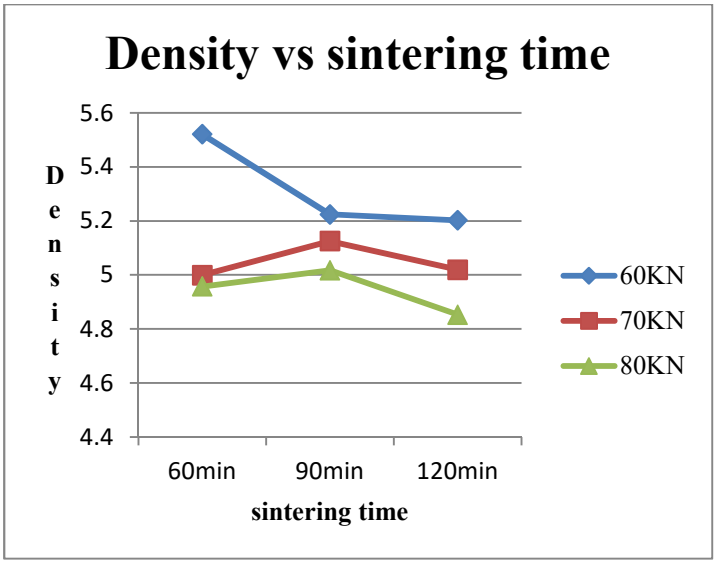

Fig 3.2 Density vs sintering time results of the specimens with the compaction loads of 60KN,70KN,80KN

The fig 3.2 shows that the density variation with the sintering time, it can be clearly seen that as the sintering time increases, the density is getting decreased, this is because as the sintering time of the material increases the porosity of the material will become lesser therefore the density will be decreased. The density variation for 60KN load decreased from 5.521 to 5.202 (g/cm^3). Similarly for 70KN load , the density got decreased from 4.4991 to 5.019(g/cm^3). Similarly for 80KN load ,density got decreased from 4.957 to 4.852(g/cm^3)..This shows that as the sintering time and compaction pressure increases the density will be reduced.

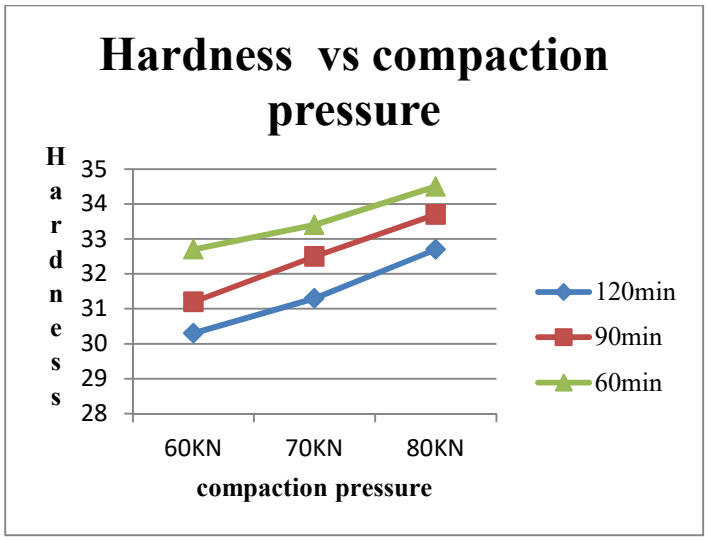

Fig3.3 Hardness vs compaction pressure results of the specimens with variation of sintering times of 60min,90min,120min.

The fig 3.3 describes the variation of hardness and the compaction pressure at 60min,90min and 120min sintering time.From the graph ,it is clear as the compaction pressure increases, then the hardness is also increasing.This is because as the pressure increases, the bonding between the molecules increases ant the material becomes harder. Therefore the hardness is getting increased as the compaction pressure increases, the hardness for 60min sintering time is varied from 30.3 to 32.7.The hardness for 90min sintering time is varied from 31.3 to 33.4.The hardness for 120min sintering time is varied from 32.7 to 34.5.

3.4 Tribological properties of NiCr and SiC based composites

The experiment process parameters are taken from below table. The wear rate ,friction force and coefficient of friction values are calculated for the 9 specimens at different conditions on pin on disc machine. From the below table we can observe clearly that the wear rate values tends to decrease from 3.1×10^{-5} mm^3/Nm to 1.1×10^{-5} mm^3/Nm. It is observed that as the compaction pressure and the sintering time increases ,the wear rate values are getting decreased[11]. This is because as the compaction pressure and the sintering time gets increased, the bonding between molecules gets increased therefore the specimen becomes harder and therefore the hardness of the specimen gets increased and the porosity of the specimen also gets decreased[18-20].As the hardness of the material gets increased the chances of the wear of the material gets decreased. Therefore the result demonstrates that specimen with the lowest compaction pressure and the lowest sintering time has the highest wear rate of 3.1×10^{-5} mm^3/Nm and the specimen with the highest compaction pressure and the highest sintering time has the lowest wear rate of 1.1×10^{-5} mm^3/Nm.

From the below mentioned table 3.2 we can observe that the coefficient of friciton values are higher for higher wear rate of about 0.58 and the coefficient of friction values are lower for the lower wear

rate of about 0.32 .This result demonstrates that as the densities of the specimens increases the coefficient of friction values decreases.(21)

Table 3.2 Representation of tribological parameters

Load(KN)	Sintering time(min)	Wear($x10^{-5}mm^3/Nm$) rate	Friction force(N)	Coefficient of friction
60	60	3.1	13.8	0.58
60	90	2.9	13.2	0.53
60	120	3.0	13.7	0.55
70	60	2.5	12.8	0.49
70	90	2.2	12.6	0.45
70	120	2.0	12.6	0.43
80	60	1.5	11.2	0.39
80	90	1.3	10.1	0.37
80	120	1.1	9.9	0.32

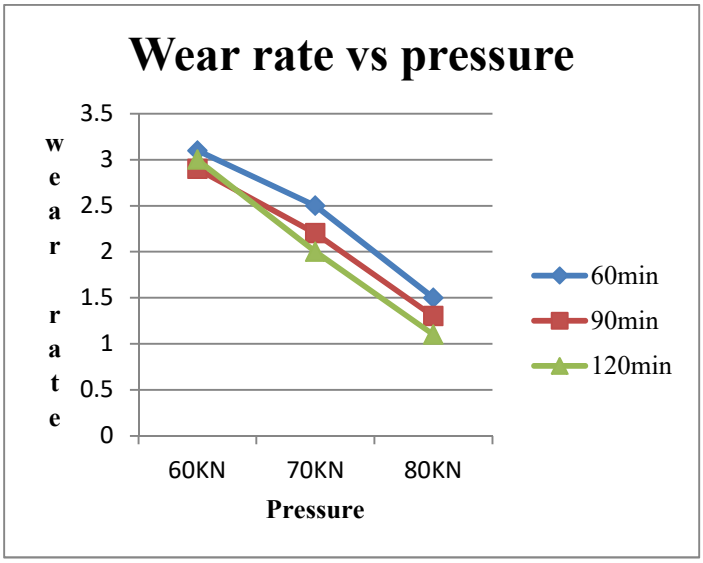

Fig 3.4 Wear rate vs compaction pressure results of the specimens with the variation of sintering times of 60min,90min,120min

From the fig 3.4 ,it is clear that as the pressure increases from 60KN to 80KN, the wear rate is getting decreased, for the sintering time of 60min the wear rate is getting decreased from (3.1 - 1.5) x 10^{-5} mm^3/Nm and for the sintering time of 90min,the wear rate is getting decreased from (2.9-1.3) x 10^{-5} mm^3/Nm and for the sintering time of 120min the wear rate is getting decreased from (3.0-1.1) x 10^{-5} mm^3/Nm. From the fig 3.4 it shows that the material with highest compaction pressure and the highest sintering time has the least wear rate of 1.1 x 10^{-5} mm^3/Nm.

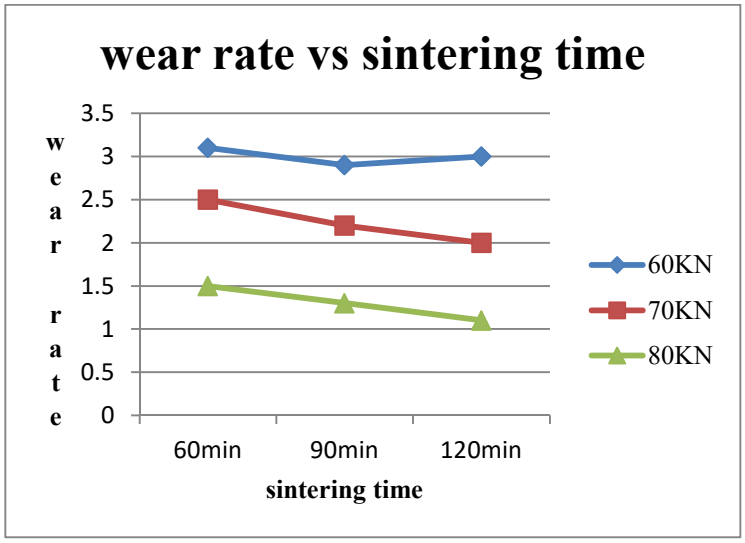

Fig 3.5 Wear rate vs sintering time results with the variation of the pressures of 60KN,70KN,80KN

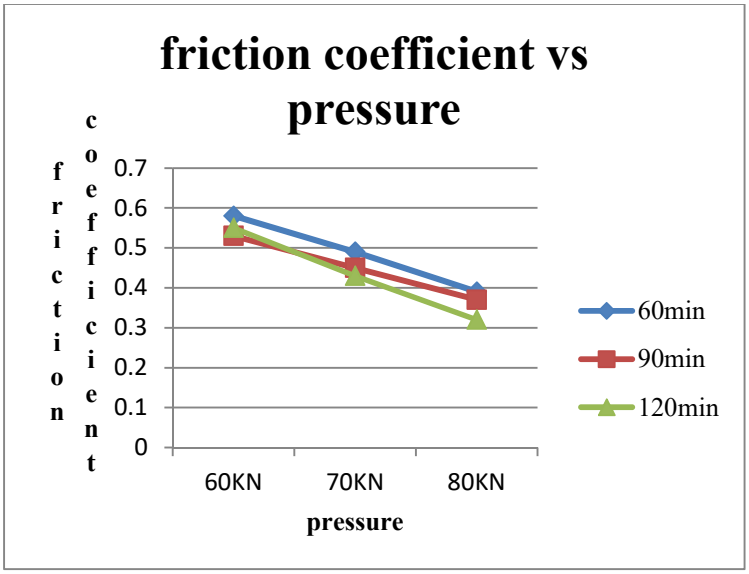

Fig 3.6 friction coefficient vs pressure results with the variation of sintering time of 60min,920min,120min

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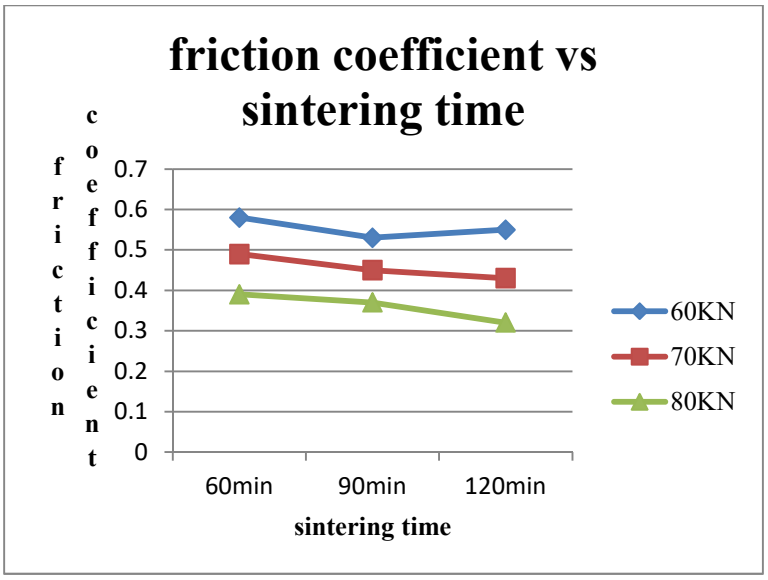

Fig 3.7 friction coefficient vs sintering time results with the variation of pressure of 60KN,70KN,80KN

From the fig 3.5 ,It is clear that as the sintering time is getting increased from 60min to 120min the wear rate is getting decreased. For the pressure of 60KN the wear rate is getting decreased from (3.1-3.0) x 10^{-5} mm^3/Nm. For the pressure of 70KN the wear rate is getting decreased from (2.5-2.0) x 10^{-5} mm^3/Nm. For the pressure of 80KN the wear rate is getting decreased from (1.5-1.1) x 10^{-5} mm^3/Nm. From fig 3.5 it shows that the material with highest compaction pressure and the highest sintering time has the least wear rate of 1.1 x 10^{-5} mm^3/Nm.

From the fig 3.6 ,it is clear that as the pressure increases from 60KN to 80KN,the friction coefficient values is getting decreased. For the sintering time of 60min ,the friction coefficient values are getting decreased from 0.58 to 0.39.For the sintering time of 90min, the friction coefficient values are getting decreased from 0.53 to 0.37.For the sintering time of 120min the friction coefficient values are getting decreased from 0.55to 0.32.From the fig 3.6 it is clear that the material with highest sintering time and the higest pressure has the least friction coefficient of 0.32.

From the fig 3.7 ,it is clear that as the sintering time increases from 60min to 120min,the friction coefficient values is getting decreased. For the pressure of 60KN the friction coefficient values are getting decreased from 0.58 to 0.55.For the pressure of 70KN load the friction coefficient values are getting decreased from 0.49 to 0.43.For the pressure of 80KN load the friction coefficient values are getting decreased from 0.39 to 0.32.From the fig 3.7 it is clear that the material with highest sintering time and the higest pressure has the least friction coefficient of 0.32.

Conclusions

The tribological studies of NiCr/SiC are being studied using wear test process ,the main conclusions of this Nicr/sic composites are as follows

1. The microstructures of the specimens are equally distributed as applied for compaction pressures of 60KN,70KN,80KN and sintering times of 60min,90min,120min.

2. The hardness of the specimen is getting increased as the pressure is getting increased.
3. The density of the specimen is getting decreased as the sintering time is getting increased.
4. The wear rate of the specimens are getting decreased when the pressure is increased and similarly the wear rate of the specimens are getting decreased when the sintering time is increased.
5. The friction coefficient values are getting decreased when the pressure is increased and similarly the friction coefficient values are getting decreased when the sintering time is increased.

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