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INVESTIGATION OF TEMPERATURE EFFECT FOR NANOCOMPOSITE MATERIALS SUBJECTED TO HIGH STRAIN RATE IMPACT

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ABSTRACT: The study coversthe dynamic impact response of nanocomposite Alumina and nanocomposite carbon black particlesCB N220/Epoxy at room temperatures and 150 ℃at five velocities (16.58, 18.24, 19.88, 21.54 and 23.2) m/s by using a Hopkinson Split compressive Bar (HSPB).The nanocomposites samples with (2wt. % and 4 wt. %) of (Alumina and CB N220) were prepared without and with (25%) of unidirectional fiber glass. The results indicated that, maximum stress, strain and absorbed energy increased with increasing the strain rate for all types of these samples at room temperature. When increase the temperature to 150 ℃ it noted that the all values of stress, strain, strain rate and absorbed energy decreased with respect the values at room temperature. The determined Johnson-Cook parameters were found as the empirical fitting for data of stress (temperature, strain, and strain rate) with the curves of stress-strain, that are obtained from the compression tests.

Keywords: *Hopkinson, strain rate, nanocomposite, Johnson-Cook.*

التحقق من تأثير درجة الحرارة على مواد نانوية معرضة الى صدم بمعدل أنفعال عالي

الخلاصة: تتضمن الدراسة تأثير الحرارة والصدمات بسرعات العالية على نوعين من المواد النانوية المركبة هما مادة الألومينا والكاربون الأسود مع الأيبوكسي عند درجة حرارة الغرفة وعند ١٥٠℃ وبأستخدام خمس سرع:,(*16.58, 18.24, ١٩,٨٨ 21.54,* و ٢٣,٢) م/ثا بأستخدام عمود هوبكنسن للكبس المجزأ .تم تحضير اربعة أنواع من العينات لكل مادة من خلال التحكم بنسبة تركيز المادة النانوية وكذلك اضافة (٢٥ %) أو عدم أضافة الألياف الزجاجية (أحادية الأتجاة) وبذلك تكون أنواع العينات هي: 2%، 4% بوجود وعدم وجود الألياف. تم خلط هذه المواد بجهاز التشتت بالموجات فوق الصوتية. بينت النتائج ان اعلى قيم للأجهاد ، الأنفعال والطاقة الممتصة تزداد بزيادة معدل الأنفعال. عند زيادة الحرارة الى ١٥٠℃ وجد أن قيم كل من الأجهاد، الأنفعال، معدل الأنفعال والطاقة الممتصة تقل بالنسبة الى قيم درجة حرارة الغرفة. تم حساب متغيرات معادلة جونسون – كوك (معادلة تربط بين الأجهاد والأنفعال ومعدل الأنفعال ودرجة الحرارة) ومن خلالها تم رسم مخطط الأجهاد والأنفعال نظرياً ومقارنته مع النتائج العملية.

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1. Introduction

Nowadays, lengthy techniques designed to study material behavior at high strain rate loadings because the properties of several materials are dependent on the strain rate subjected on the metal. The Hopkinson Split Pressure Bar (HSPB) system is very activated. It is used to apply high rate of strain in different engineering materials under tension, compression, and torsion state with rates of strain reach to $10^4 s^{-1}$[1]. Ha T.T Phan (2012)[1] investigated the dynamic behaviors of Graphene-Poly-urethane composite at strain rate from $1500\,s^{-1}$ to $5000\,s^{-1}$ with (0.25, 0.5, 0.75, 1) %GR concentrations. The results showed that a Graphene-Poly-urethane at 0.5% weight fraction specimen has maximum peak stress, and the Graphene-Poly-urethane at 0.1% weight fraction specimen has highest plateau stress. Prashant Jindal(2013)[2]studied Polycarbonate (PC) based composites fabricated with different concentrations with 0.1, 0.5 and 1% by weight of Multi Walled Carbon Nanotubes (MWCNTs) under varying strain rates ranging from 1096/s to 4017/s. It was found that the maximum strain produced increased with increased in strain rate.Antonio F. Ávilaet al [3] studied the dynamic behavior of two nanocomposites: glassfiber epoxy with nanoclay and glass fiber epoxy with nanoflakes graphite. Results showed that the addition nanoclay and nanoflakes graphite to fiber glass/epoxy laminates will be increase the impact velocity resistance composites and has effect on mechanism of failure. M.K. Habibiet al (2012)[4]studied the response of nanocomposites magnesium at rate of strain $10^{-4}s^{-1}$ and $2\times 10^3 s^{-1}$. When the strain rate increases the strength of nanocomposites magnesium will be increase in compression and tension. Also, the increases of stress compare with static rates resultant in an increase in absorption energy.

The aim of this research is to develop of SHBV compression by adding heater in the region of the specimen to study thermal effect and test samples made from composite material with added nanocomposite materials under high strain rate impact also use Johnson-Cook model for verifying the experimental results.

2.Experimantal Work

2.1. Material Properties

In present work, nanoparticle Alumina and CB N220 by 2% wt. and 4% wt. without and with (25%) unidirectional fiberglass with resin (epoxy) are used to prepared samples. Table (1) shows the physical properties of epoxy resin and fiberglass (Euxit 50 KI). Table (2) shows list of the physical properties of nanoparticle used in present work.

Table (1): List of Properties of Epoxy and Fiberglass

Properties	fiberglass [5]	resin (epoxy) [6]
Diameter (mm)	1-2	-----
Density (gm/cm^3)	2.52-2.62	1.05
Modulus of Elasticity (GPa)	76	2.8
Poisson ratio	0.22	-----
Mix ratio (by weight)		1:3
strength (MPa)	1.4-2.5(typical)/3.5(freshly drown)	45

Table (2): Physical Properties of Nanoparticle used in the Experimental Work

Properties	Alumina [7]	CB N220 [6]
Purity	> 99.5	
O.D.(nm)	20-50	24-26
Density	> 3.7	355 ±20
SSA(Specific Surface Area)	-	106-116
Hardness (GPa)	23	
Compressive Strength (GPa)	3500	
Bending Strength (MPa)	300	
Young Modulus (GPa)	380	
Poisson number	0.22	
Maximal operating temperature (°C)	1950	
Color	White	Black

2.2. Preparation of Samples

1- The nanocomposite particles mixed with the resin (epoxy) for 15 minute at 25 C^o slowly and continuously using the mixture (Fig.1A) to prevent bubbling yields from the process to reach a uniform state: Intermingling the combination by ultrasonic wave route machine (U.S.W.){ model (LUC) (Power Sonic 410) (400W ,50Hz and 220 V)} (Fig.1B) for 50 minutes to prevent heat produced during the process, that is influent the epoxy's properties and to scatter the nanoparticles.
2- Glass mold of (15mm diameter and 180mm length) with opened end was used. Lubricate the tube walls by oil then the fiber glass with (25% volume fraction) are arranged in the mold in the homogenous form to cover most volume of the sample.
3- Finally, the test samples will be obtained by cutting the samples to 7.5mm length according to the slender ratio (Ls/Ds) of 2 [8]. Figure (2) shows the samples used in the present work

A: Mixture

B: U.S.W.

Fig (1): Mixing of Nanocomposite

Figure (2): The samples used in present work.

2.3. The Test Rig

The compression SHPB used in this study is shown with details in Fig.(3).It consists of two homologous bars located in arrangement with the sample between these bars (see Fig.4A).The striker bar is struck by incident bar during the test. The shooter gun is rushes the striker bar. The transmitted bar shocked with a big block of soft metal. Two gages of strain are fixed on both the transmitted and incident bars. The stress, strain, strain rate and absorbed energy are calculated from the output signals. To study the temperature effect on the behavior of the composite specimen, the heat is applied on the specimen. The oven connects with variac which is used to get the desired temperature.

The strain gages are placed on the output and input bars to find [9]:

1. The incident bar oscillation formed by the projectile. 2. The transmitted bar oscillation from the specimen to the output bar. 3. The reflected oscillation bar from interface of the input bar and specimen.

Figure (4B) shows the instrumentations used and Figure (4C) shows the output signal during test.

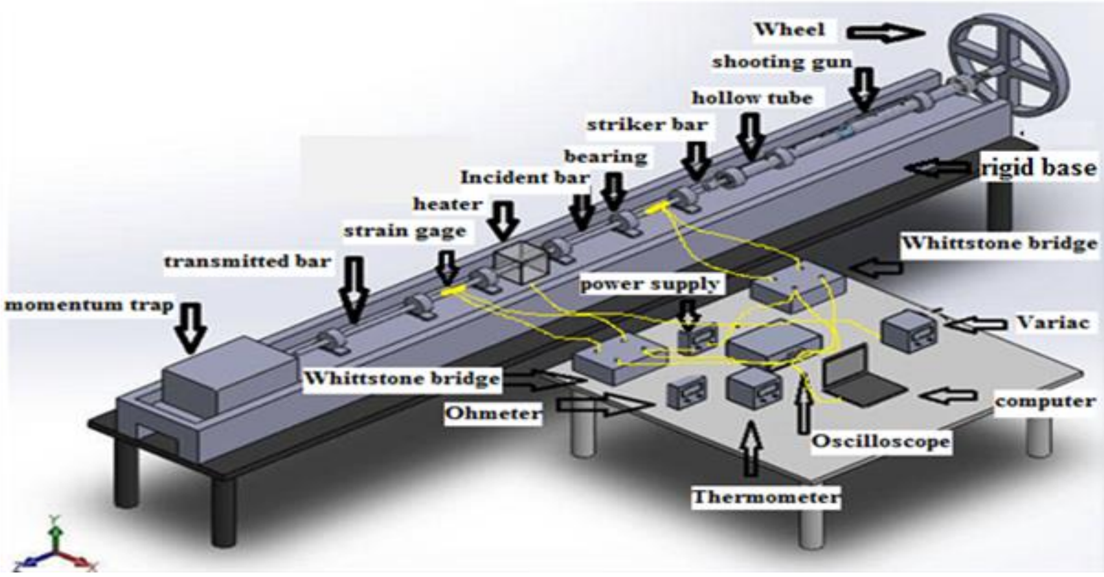
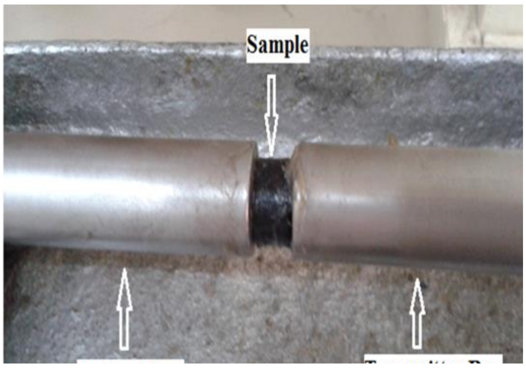
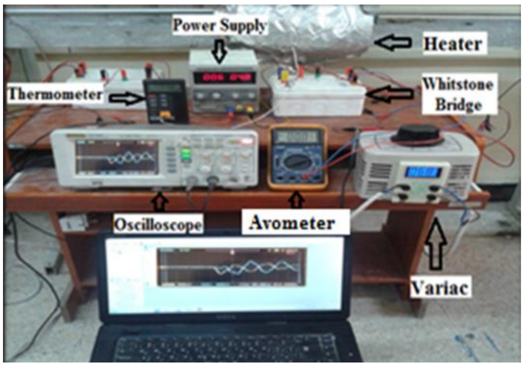


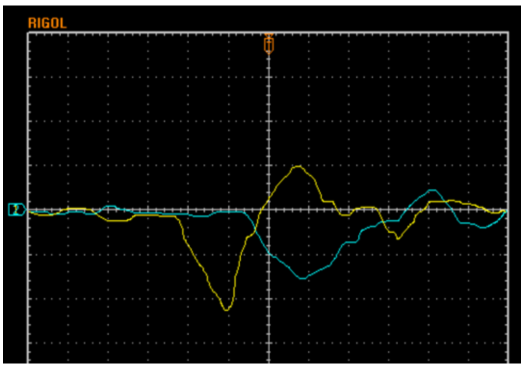
Fig (3): Schematic diagram of Hopkinson Split Pressure Bar for Compression Test



A- Sample between bars



B- Test Rig



C: Output Signal

Fig (4): During Test

2.4. Quasi-Static Compression

A compression test is very important to find the mechanical properties of materials at strain rates (ε° = 10^{-2}1/s). The compression tests were done using universal mechanical test (TINIUS OISEN H50KT). The shape and dimensions of the compression test specimen and the procedure of test have been down according to (ASTM-D695M-89) standards [10].

3. Calculation of the Specimen Stress, Strain-Rate, Strain and Absorbed Energy

The analytical relations to calculate stress, strain and strain rate with time in the specimen are [9]:
Expression for average stress of the specimen is:

$$\sigma_{AVG}(t) = \frac{A_b}{A_S}\varepsilon_T(t)E \qquad (1)$$

The specimen strain rate expression is:

$$\dot{\varepsilon} = \frac{-2c}{L}\varepsilon_R(t) \qquad (2)$$

This equation is integrated to find the specimen strain

$$\varepsilon_s(t) = \frac{-2c}{L}\int \varepsilon_R\,(t)\,dt \qquad (3)$$

The amount of energy that can be absorbed by the specimen can be calculated using the area under the curve of the force verses time multiplied by the impact velocity as in the following equation:

$$E_o = \int F_{AVG} * Vdt \qquad (4)$$

Therefore; the absorbed energy depends on the specimen stress, impact velocity and dimensions of sample (area and thickness).

4. Johnson Cook Model

Johnson and Cook [11] was introduced the Johnson-Cook model. The determined Johnson-Cook parameters were found as the empirical fitting for data of (stress temperature, strain, and strain rate) with the curves of stress-strain, that are obtained from the compression tests. The Johnson – Cook Model is

$$\sigma = [A+B\epsilon^{n}]\,[1+C\ln\dot{\epsilon}^{*}]\,[1-(T^{*})^{m}] \quad (5)$$

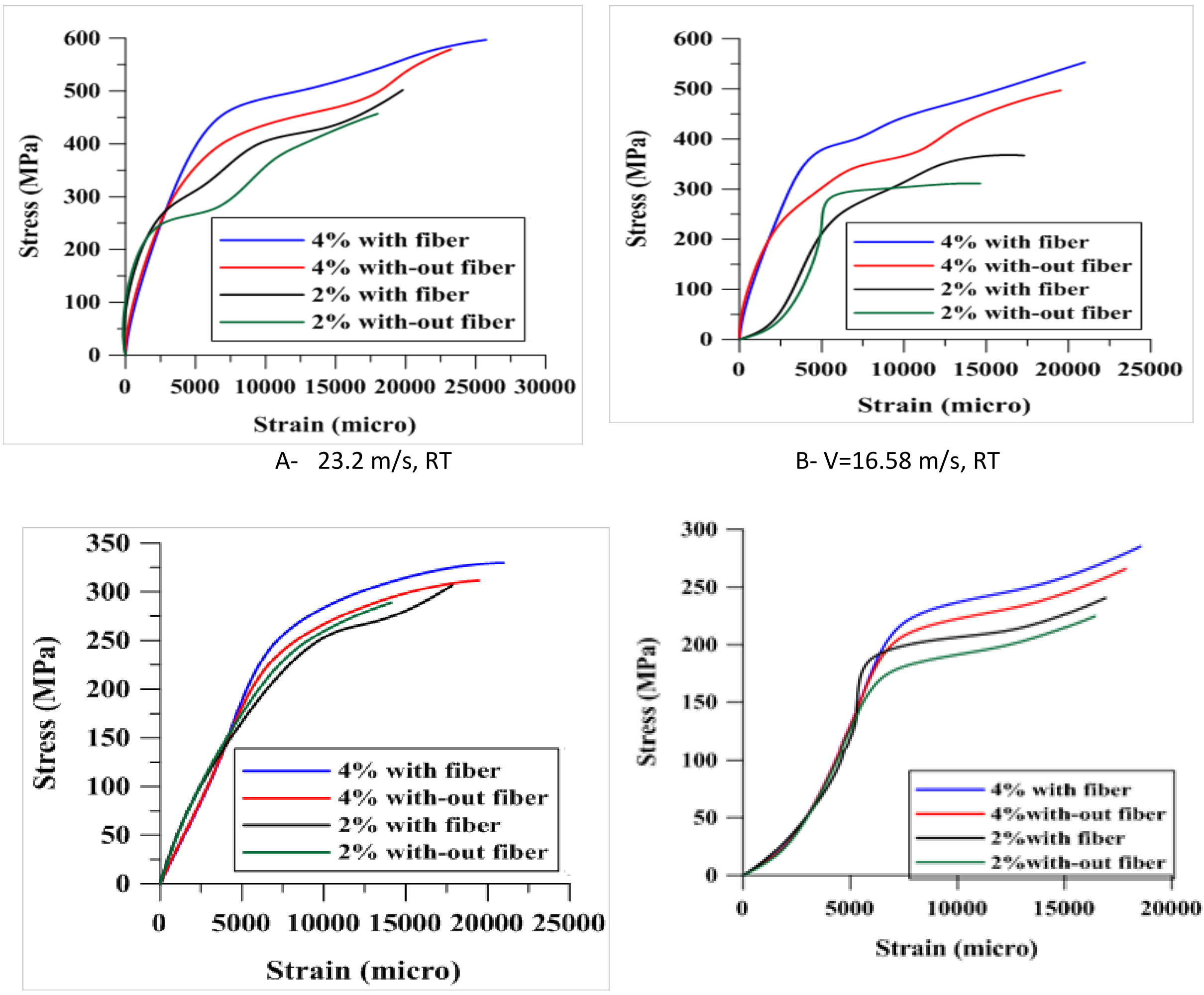
The stress was found as a function of strain in the first part of the above expressions when $T^{*}=0$ and $\dot{\epsilon}^{*}= 1.0$. The effects of strain rate and temperature are shown in the second and third part of the expressions respectively. The stress become near to zero when melting temperature = 1.0 for all strain rates and strains.

5. Results and Discussion

5.1. Stress, Strain and Strain rate

Figure (5 A, B, C and D) show the relation between stress and strain with different types of samples at room temperature and at T=150 ℃ at impact velocity (16.58 m/s) and (23.2 m/s) velocity respectively. For nanocomposite CB N220 and at V=16.58 m/s the stress: 311MPa, strain: 14623 μs strain rate: $722 s^{-1}$.

Then the other cases are increasing with respect to these values when increasing velocity, add nanoparticle and add fibers for room temperature and T=150 ℃ .



A- 23.2 m/s, RT

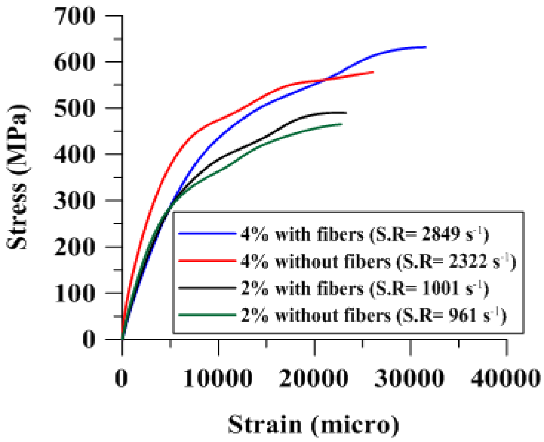
B- V=16.58 m/s, RT

C-V= 23.2 m/s, T= 150 ℃

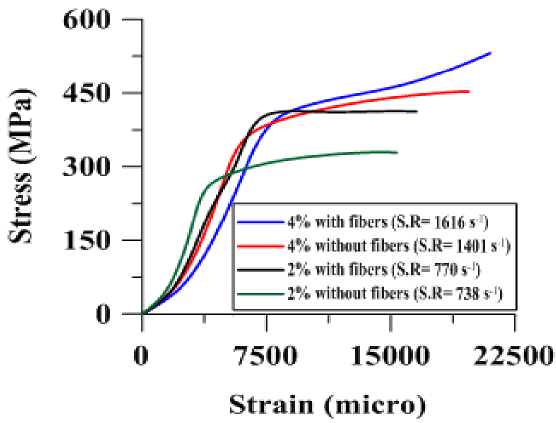
D- V=16.58 m/s, T=150 ℃

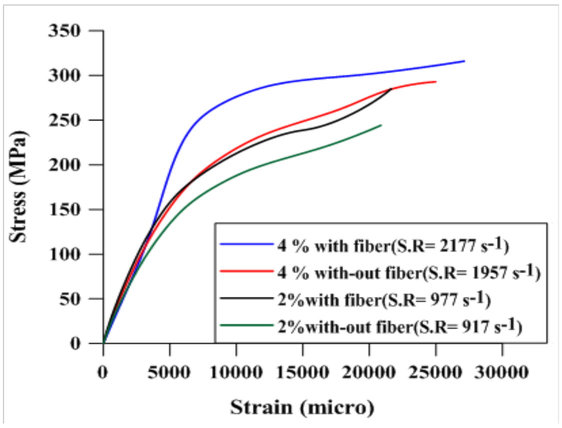
Fig (5): Dynamic Stress- Strain curves behavior for nanocomposite CB N220/Epoxy with different temperature and different strain rate

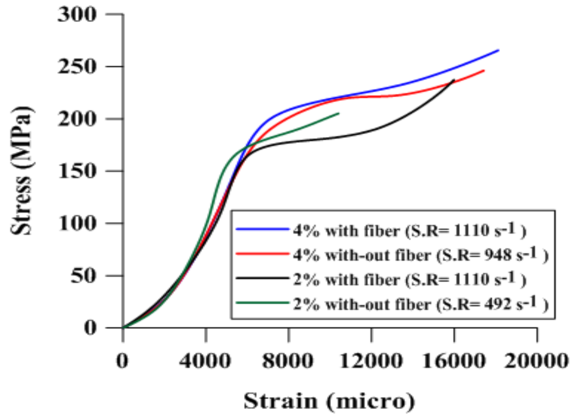
Figures (6) give the effect of strain rate on stress and strain for all cases at room temperature and at T=150 ℃ with minimum and maximum velocity.V=23.2 m/s, the results of maximum values for nanocomposite Alumina for 2% with without fiber. The stress is 465MPa, strains is 22719 μs and strain rate $961 s^{-1}$. Then the other cases are increasing with respect to these values when increasing velocity, add nanoparticle and add fibers for room temperature and T=150 ℃ .



V=23.2 m/s, RT







B- 16.58 m/s, RT

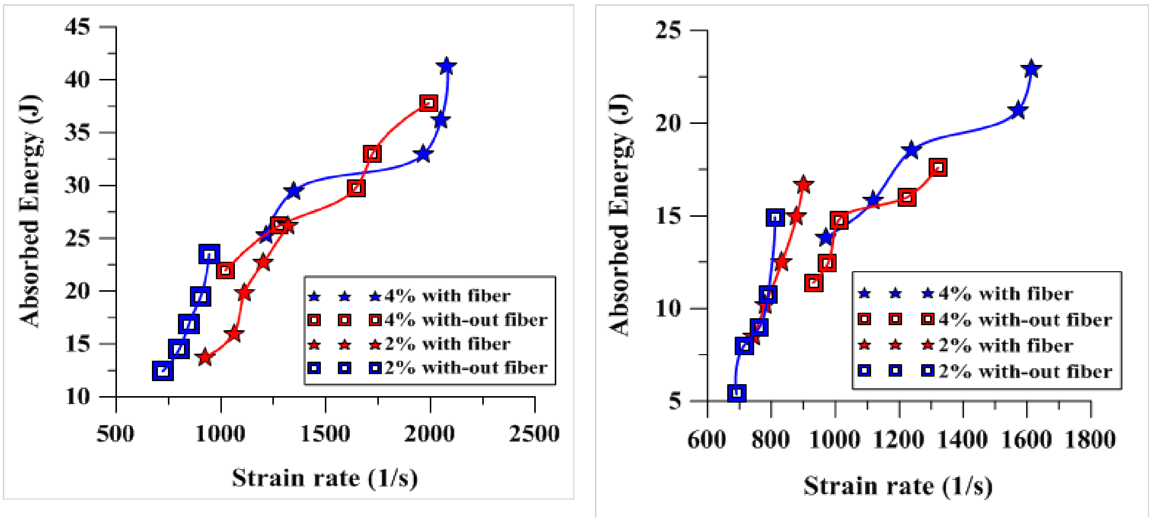
C-V= 23.2 m/s, T= 150 ℃

D- V=16.58 m/s, T=150 ℃

Fig. (6): Dynamic Stress-Strain behavior for nanocomposite Alumina/Epoxy with different strain rate and different temperature

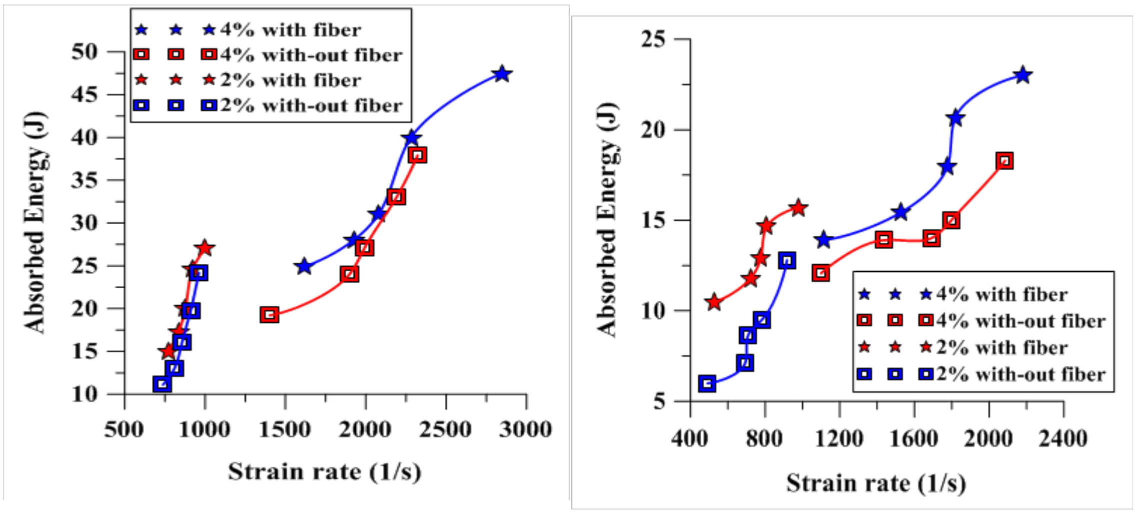
4.2. Absorbed Energy

The total and absorbed energy for each test is determined and examined in this investigation. The absorbed energy is increased with increasing the strain rate which in turn is increasing with impact velocity. The result of energy at V=23.2 and for 2%Alumina without fiber 24.2J at RT. Also, 23.48J for CB N220 at RT. Figures (7,8) show the effect of strain rate on absorbed energy at room and at T=150 ℃ for nanocomposite Alumina and CB N220 at all cases respectively.



A B

Fig. (7): Maximum Strain rate effect on Absorbed Energy for all cases for nanocomposite Alumina/Epoxy for all cases of samples at (A-RT, B- T=150℃)

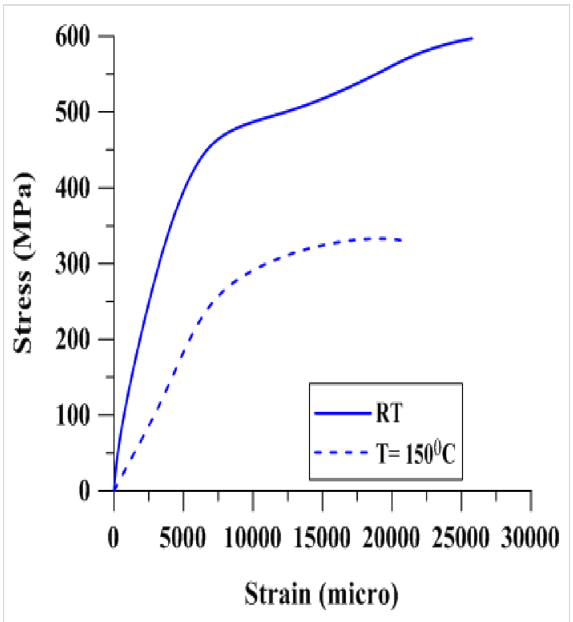


A B

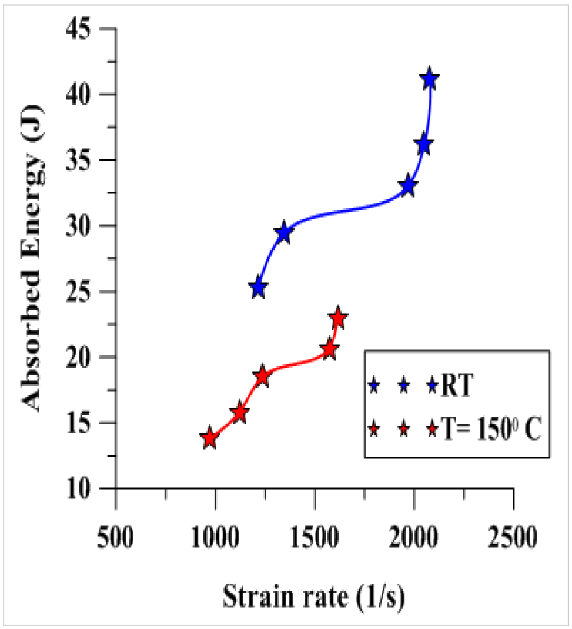
Fig. (8): Effect of Maximum Strain rate on Absorbed Energy for nanocomposite CB N220/Epoxy for all cases of samples at: (A- RT, B- T=150 ℃)

4.3. Comparison between Room Temperature and T=150 ℃

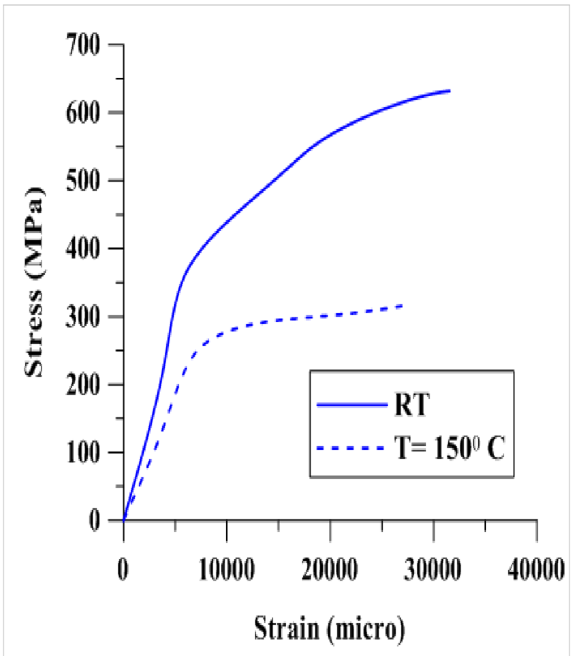
For samples have 4% nanoparticle with fiber and at V=23.2 m/s, nanocomposite CB N220 the percentage dropped in stress, strain and A.E. are 44.7% and strain 18.51%, and 44.49%respectively. Also, nanocomposite Alumina inclined in the stress 50%, strain 14% and absorbed energy 51.579% because the strength of samples became weak and cannot withstand the same force when applied at room temperature, this belong to the bounded between atoms and microstructure for samples are very weak [1]. Figures (9) give the effect of temperature on materials used in present work.



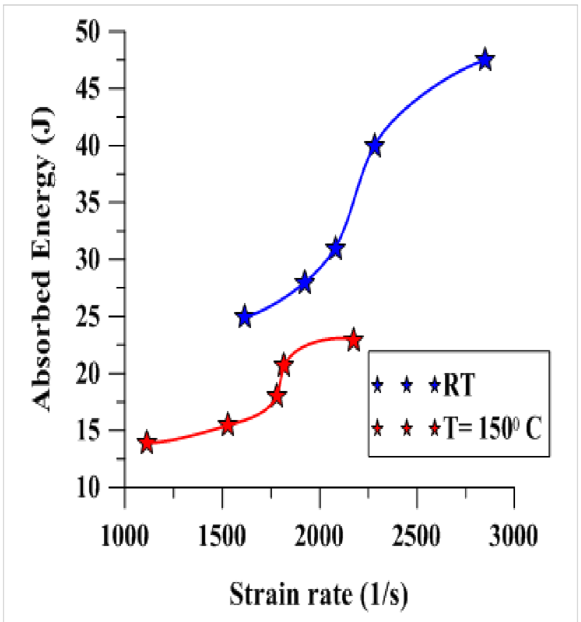
A



B



C



D

Fig. (9): Comparison between RT and T=150 °C for nanocomposite

A- Stress-Strain behavior for CB N220/Epoxy

B- Variation of Absorbed Energy with Maximum strain rate for CB N220/Epoxy

C- Stress-Strain behavior for Alumina/Epoxy

D-Variation of Absorbed Energy with Maximum strain rate for Alumina/Epoxy

Tables (3&4) give all information about incremental percentage for nanocomposite CB N220 and Alumina for all cases (incremental percentage for samples with fibers w.r.t samples without fibers, incremental percentage w.r.t increase nanoparticle, incremental percentage w.r.t change velocity from (16.58∼23.2) m/s and decremented percentage w.r.t increasing temperature (T=150℃/RT)) at room temperature and T=150 ℃.

Table (3): Incremental Percentageof Mechanical Properties for Nanocomposite CB N220 for with different variables (Increasing Velocity, Increasing Temperature, add fibers and Increasing concentration of Nano powder)

CB N220 Nano composite	with fibers/ without fibers and w.r.t. increase nanoparticle in V=23.2 m/s							
Mechanical Properties (%)	RT		T=150 ℃		RT		T=150 ℃	
	4%	2%	4%	2%	w.f.	w.o.f	w.f.	w.o.f
σ (MPa)	3.1	9.8	7.5	6.22	18.9	26.7	7.511	7.95
ε (μs)	10.87	10	7.8	26.26	30	29	7.6	37.7
$\varepsilon^{\circ}(s^{-1})$	4.47	39.9	22.18	11	57.4	111	79.2	62.88
A.E.(J)	9.1	11.79	30.1	11.78	57	60.9	37.2	17.88
Mechanical Properties (%)	w.r.t change velocity from (16.58~23.2) m/s							
	RT				T=150 ℃			
	2%	2%F	4%	4%F	2%	2%F	4%	4%F
σ (MPa)	46.9	36.78	16.5	7.95	44.5	38.9	22.3	18.2
ε (μs)	23	14.47	19	22.7	14.7	16.6	6.6	9.19
$\varepsilon^{\circ}(s^{-1})$	30.7	43.12	94.8	71.4	17.36	57.7	41.9	66.2
A.E.(J)	89	91.46	71.96	63	177.5	96.3	47.5	65.5
Mechanical	w.r.t. increasing temperature (T= 150 ℃/RT)							
Properties (%)	2%		2%F		4%		4%F	
σ (MPa)	36.76		38.8		46		44.7	
ε (μs)	27.4		11		16.23		18.5	
$\varepsilon^{\circ}(s^{-1})$	14		31.8		33.65		22.4	
A.E.(J)	36.4		36.4		53.4		44.5	

Table (4) Incremental Percentage of Mechanical Properties for Nanocomposite Alumina for with different variables (Increasing Velocity, Increasing Temperature, add fibers and Increasing concentration of Nano powder)

Alumina Nano composite	with fibers/ without fibers and w.r.t. increase nanoparticle in V=23.2 m/s							
Mechanical Properties (%)	RT		T=150 ℃		RT		T=150 ℃	
	4%	2%	4%	2%	w.f.	w.o.f	w.f.	w.o.f
σ (MPa)	9.3	5	7.8	16.8	29	24.3	10.8	20
ε (μs)	21	2.3	8.5	3.7	35.6	14.6	25	19.7
$\varepsilon^{\circ}(s^{-1})$	22.7	4.1	4.4	6.5	184	141	122	127
A.E.(J)	25.5	11.57	25.6	54.3	75.9	56.6	46	43
Mechanical Properties (%)	w.r.t change velocity from (16.58~23.2) m/s							
	RT				T=150 ℃			
	2%	2%F	4%	4%F	2%	2%F	4%	4%F
σ (MPa)	49.5	19	27.6	19	19	104	19.1	18.9
ε (μs)	47.9	40.6	32.3	50.1	100	35	43.4	49.7
$\varepsilon^{\circ}(s^{-1})$	30.2	30	65.7	76.3	86.3	84.7	89.7	96
A.E.(J)	118	80	97.3	90.7	113	48	51.6	65
Mechanical Properties (%)	w.r.t. increasing temperature (T= 150 ℃/RT)							
	2%		2%F		4%		4%F	
σ (MPa)	47.5		41.8		49.3		50	
ε (μs)	8.2		7		4.11		14	
$\varepsilon^{\circ}(s^{-1})$	4.6		2.4		10.2		30.86	
A.E.(J)	47.1		41.85		51.72		51.58	

4.4. Analytical Assessment of Results

The dynamic compression test results for 4% concentration of nanoparticle with adding unidirectional fiber glass tested materials were assessed using Johnson Cook model was used to identify the stress-strain behavior theoretically of 4% with fiber Alumina /epoxy at strain rate of 2849 1/s. Based on, Johnson Cook model the following equation can be obtained for 4% with fiber :

$$\sigma = \left[125.2 + 112.2\varepsilon_p^{0.427}\right]\left[1 + 0.24553 ln\varepsilon^{\circ *}\right] \quad (6)$$

The results of experimental coincide well with the constitutive curve.

Figure (10) shown stress-strain curves for nanocomposite materials used in present work under Quasi – Static compression test and table (5) described the values of constants for J.C.E. Figures (11) show a comparison between experimental results and results using Johnson Cook model for 4% nanocomposite Alumina/ Epoxy with fiber at room temperature.

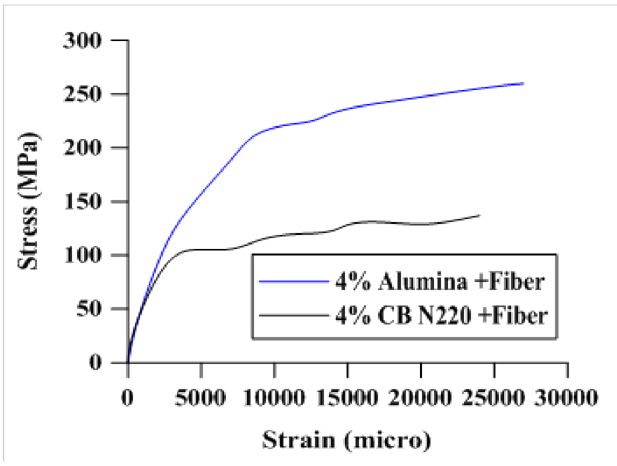
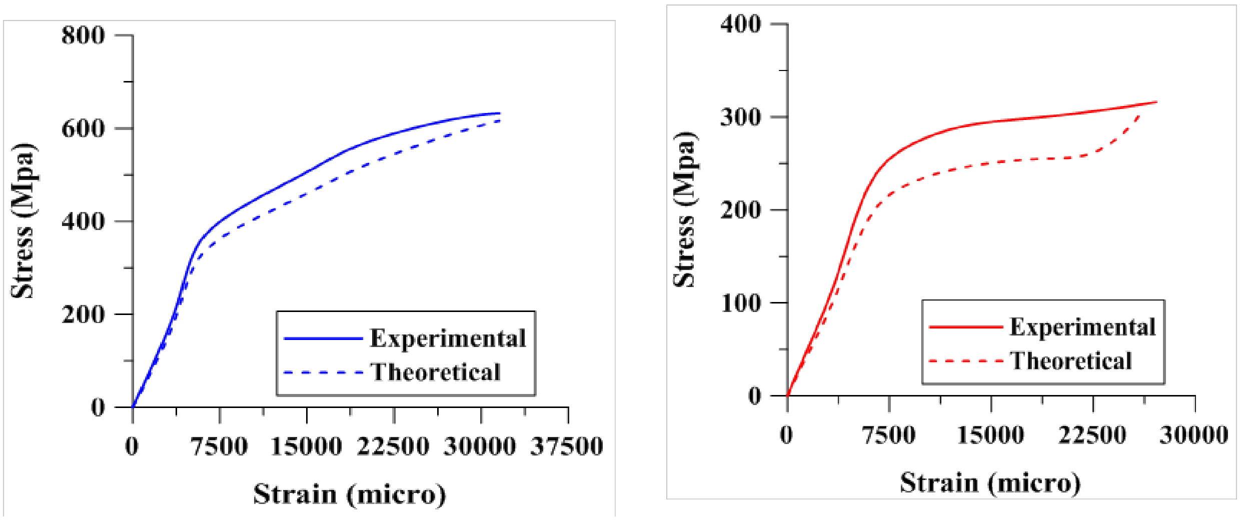


Fig. (10): Stress-Strain curves for nanocomposite materials used in present work under Quasi- Static Test



A B

Fig (11): Stress –Strain curve Comparison between experimental and theoretical for Alumina in maximum velocity at: A - Room Temperature, B- T=150°C .

Table (5): The Values of Parameter for Johnson- Cook Equation $\sigma = [A+B\epsilon^{n}]\ [1+C\ln\dot{\epsilon}^{*}]\ [1-(T^{*})^{m}]$

4%+fibers	A (MPa) B (MPa) C m
Alumina	125.2 112.2 0.24553
CB N220	0.427 0.643
	103 95.5 0.9439
	0.354 1.1377

5. Conclusions

1. The stress, strain, strain rate and absorbed energy are decrease with increase temperature for nanocomposite (Alumina and Carbon Black (CB N220)) with and without fibers.
2. The maximum dynamic compressive stress, maximum strain and absorbed energy are increases with increases the strain rate.
3. Addition nanoparticle (Alumina and CB N220) to epoxy and fiber-glass epoxy composite is improvement and catalyze the values of stress, strain, strain rate and absorbed energy of these samples.
4. Addition Alumina nanoparticle to composite samples (epoxy and epoxy fiber glass composite) is improvement the properties compared with added CB N220.
5. The epoxy, epoxy fiber glass samples with add 4% nanoparticle (Alumina and CB N220) gives stress, strain, strain rate and absorbed energy greater than samples with 2% nanoparticle.
6. Fiber-glass samples with 4% nanoparticle at room temperature improvement the absorbed energy by: 206% for alumina and 165.78% for CB N220 compared with fiber glass samples without nanoparticle.
7. At temperature (T=150℃) also (same paragraph 6) but absorbed energy declined with respect room temperature by: 51.579%, 40.8% and 44.49% for alumina, S-glass and CB N220 respectively.
8. Johnson-Cook gives good agreement with experimental work with maximum error by 15% and 9% at room temperature and T=150℃.

Abbreviations

ϵ	the equivalent plastic strain,
$\mathring{\epsilon}$	Strain rate,
$\mathring{\epsilon}^{*} = \mathring{\epsilon}/\mathring{\epsilon}_0$	The plastic strain rate dimensionless for $\mathring{\epsilon}_0 = 1.0s^{-1}$
T^{*}	The homologous temperature= $T - T_{ROOM} / T_{MELT} - T_{ROOM}$
A	Yield stress
B and n	Effects of strain hardening
C	Strain rate constant
M	Thermal softening fraction
RM	Room Temperature

Ls	length of sample
Ds	diameter of sample
E	modulus of elasticity
σ_{AVE}	Average stress
A_b	Area of bar
A_s	Area of sample
c	wave velocity
ε_R	Reflected strain
ε_T	Transmitted strain
E_O	Absorbed energy
F_{AVE}	Average force
V	velocity

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