Effect of Strain Rate on Metal Flow for Different Materials

Renwar Mohammed Amin Qadir

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Contents

Abstract

Strain rate or deformation velocity plays an important role inindustrial deformation processes. Thus the influence of strain rate onthe flow stress must be investigated to measure it significance. To measure this influence of a metal it is necessary to carry out individual tensile tests at a constant strain rate. A tensile test is normally carried out at room temperature and the time taken for the test is quite long when compared with industrial deformation time cycles.The principal advantaged of the tensile test are, it is an easy test to carry out and the specimen is subjected only to a uniaxial stress.

In this project, the effect of two-strain rate (0.0018 & 0.0025 sec^{-1}) on the flow stress for three different test specimen materials (steel, brass & bronze) were studied. It was found that as the strain rate is increased the flow stress of the metal is decreased for all three-specimen materials.

Chapter 1
Theoretical part

1.1: The tensile test:

A test-piece of known cross-sectional area is gripped in the jaws of a testing-machine, and is subjected to a tensile force, which is increased by which the length of a known" gauge length" on the test-piece increases is measured using a suitable extensometer. When the test-piece begins to stretch rapidly, Theextensometer is removed rapid extension is a sign that fracture is imminent, and failure to remove the extensometer from the test-piece would probably lead to the destruction of the extensometer. The maximum force applied to the test-piece before fracture is measured.

A force /extension diagram can then be plotted (fig, 1.1). At first, the amount of extension is very small, compared with the increase in force. Such extension as there is directly proportional to the force, that is, *OA* is a straight line. If the force is released at any point before*A* is released, the test piece will return to its original length. Thus the extension between *O&A* is elastic, and the material obeys Hooke's Law:

Stress α Strain

Or

Stress / Strain = a constant (E)

This constant, E, is known as Young's Modulus of Elasticity for the material.

If the test-piece is stressed past the point *A* (known as the elastic limit or limit of proportionality), the material suddenly "gives"; that is suffers a sudden extension for very little increase in force. This is called yield point (Y), and, if the force is now removed, a small permanent extension will remain in the material.Any extension, which occurs past the point, *A* is of a plastic nature.As the force is increased further, the material stretched rapidly first uniformly along its entire length, and then locally to form a"neck". This "necking" occurs just after the maximum force has been reached, at *M*, and since the cross-section decreases rapidly at the neck, the force at *B* required to break the specimen is much less than the maximum load at *M*. This might be an appropriate moment topoint out the difference between a force/extension diagrams stress/strain diagram, since the terms are often loosely andimprecisely used. Fig. (1.1) clearly represents a force/ extension diagram, since the total force is plotted against the total extension,and, as the force decreases past the point *M,* for the reasonsmentioned above, this decrease is indicated by the diagram. lf, however, we wished to plot stress (force applied per unit area of cross-sectional of the specimen, as well as its length, for each increment of force. This would be particularly important for values of force after the point *M,* since in this part of the test the diameter is decreasing rapidly, due to the formation of the "neck". Just as achain is only as strong as its weakest link, so the test-piece is only asstrong as the force its minimum diameter will support.Thus, if stress were calculated on this decreasing diameter, the resulting stress/strain diagram would follow a path as indicated by the broken line to *B1*.In practice, however, a nominal value of the tensile strength of a material is calculated, using the maximum force (at *M)* and the original cross-sectional area of the test-piece. Thus,

Tensile strength = maximum force used/original area of cross-section

The term" engineering stress" is often used; it signifies the force at any stage of the loading cycle divided by the original area of cross-section of the material.

Tensile strength is a useful guide to the mechanical properties of a material. It is primarily an aid to quality control because it is a test, which can be carried out under easily standardized conditions, but it is not of paramount importance in engineering design. After all, the engineer is not particularlyinterested in the material once plastic flow begins-unless he happens to be a production engineer interested in deep-drawing, or some other forming process. In terms of structural or constructional engineering, the elastic limit, A, will be of far greater significance. (1)

1.1.1: True stress and true strain:

The engineering strain -stress curve does not give a true indication of the deformation characteristics of material because it is based ontirely on the original dimensions of the specimen , and these dimensions change continuously during the test .

Also in metal working processes , such as wire drawing the workpiece undergoes appreciable change in cross — sectional area measures of stress and strain which are based on the instantaneous dimensions are needed . Since dimensional changes are small in elastic deformation. (I)

$$\varepsilon = Ln(e + 1)$$

Where:

ε = true strain.

e = engineering linear strain

1.1.1: Tensile strength (σu):

The peak of the strain - stress curve is considered the ultimatetensile strength. Sometimes called the ultimate strength or, simply,the tensile strength. At this point during the test the highest apparent stress on a test bar of the material is measured. The curve appears to drop off after the peak. Which may be interpreted as a lower stress in the test bar. However, notice that the instrumentation used to create the diagram is actually plotting load versus deflection rather than true stress versus strain. The apparent stress is computed by dividing the load by the original cross — sectional area of the test bar. After the peak of curve is reached, there is a pronounced decrease in the bars diameter, referred to as necking down. Thus the load acts over a smaller area, and the actual stress continues to increase until failure.It's very difficult to follow the reduction in diameter during the necking down process, so it has become customary to use the peak of the curve as the tensile strength, although it's a more conservative value. (7)

1.1.2: Yield strength (σ y):

That portion of the stress—strain diagram where there is a large increase in strain with little or no increase in stress is called the yield strength. This property indicates that the material has, in fact, yielded or elongated plastically, permanently, and to a large degree. If the point of yielding is quite noticeable, as in figure (4.1), the property is called the yield point rather than the yield strength . (7)

1.1.3: Elastic limit:

At some point, called the elastic limit, material experiences some amount of plastic strain and thus will not return to its original shape after release the load. Below that level, the material behaves completely elastically. The proportional limit and elastic limit lie quite close to the yield strength. Because they are difficult to determine. They are rarely reported. (7)

1.1.4: Modulus of elasticity (E):

For that part of the stress — strain diagram that is straight, stress is proportional to strain and the value of (E) is the constant of proportionality. That is,

$$E = \text{stress/strain} = \sigma/\varepsilon$$

This is the slope of the straight-line portion of the diagram. The modulus of elasticity indicates the stiffness of the material, or its resistance to deformation. (7)

1.1.5: Ductility & percent elongation:

Ductility is the degree to which a material will deform before ultimate fracture. The opposite of ductility is brittleness. When ductile materials are used in machine members, impending failure is detected easily and sudden failure is unlikely. Also, ductile materials normally resist the repeated load on machine elements better than brittle materials. (7)

$$\text{Percent elongation} = \{(L_f - L_o) / L_o\} * 100\ \%$$

1.8: Brittleness:

A property opposite ductility is brittleness, i.e.: the ability of a material to fracture without any appreciable permanent deformation. Material possessing this property are called brittle, for such materials, the amount of elongation at rupture does not exceed (2 to 5) percent, and in some cases it is expressed by a fraction of one percent, Brittle material include cast iron, high carbon tool steel, glass, brick, stone, etc.

The tension test diagram for brittle material has no yield point or stain-hardening zone. (6)

1.2: Strain Rate

A tensile test is normally carried out at room temperature and the time taken for the test is quite long when compared with industrial deformation time cycles.

Strain rate or deformation velocity is defined as the amount of strain or deformation achieved, divided by the time required to carry out the deformation

$$\textbf{Strain rate } \dot{\varepsilon} = \varepsilon / t$$

Where $\dot{\varepsilon}$ is strain rates can be calculated for mechanical tests and industrial operation, these are:

Tensile Test	$10^{-3}\ s^{-1}$
Impact Test	$10^{-3}\ s^{-1}$
Rolling	30 s^{-1}

Generally an increase in the rate of straining of the material will, irrespective of the method of testing, increase the strain hardening effect and therefore raise the level of the flow stress.(6)

1.9: Effect of time on mechanical characteristics of Materials:

The duration of loading have a very great effect on ductility and brittleness under rapid loading; brittleness is displayed more sharply, while under prolonged loading ductility is more pronounced.

The speeds of loading and duration of external forces vary over a wide range. There are loads varying very slowly and rapidly varying loads. Some loads act for years and others for millionth fraction of a second.

It is clear that the mechanical properties of materials will differ depending on the various conditions.

A generalizing analysis of material properties taking account of time effects is very complicated cannot be confined to simple experimental curves similar to tension test diagrams.

The functional relationship of four parameters (σ), (ε), temperature (t°) and time (t). (6)

$$F(\sigma, \varepsilon, t^{\circ}, t) = 0$$

1.6: Elasticity and Plasticity:

Materials under low stresses do not suffer any appreciable permanent change of form, recovering their original form after the removal of load.

Under such condition they are said to be elastic. Under high stress materials do suffer somewhat plastic. A plastic material does not recover its shape after removal of load, reaching equilibrium after a certain amount of distortion. It does not change form continuously as load is applied, as does a viscous liquid. Under increasing load the change from a state of nearly perfect elasticity to one of aconsiderable degree of plasticity take place suddenly for some materials, especially steel, wrought iron, and some rolled or hammered metals; such metals are said to have a well-defined yield point. Other materials, such as timber, concrete, and cast iron, show a mixture of elastic and plastic action even under low loads, but do no exhibit nearly so great a degree of plastic action at high loads as do the materials noted above. (3)

1.10: Elastic and Plastic Behaviors:

Experience shows that all solid materials can be deformed when subjected to external load. It is further found that up to certain limiting loads a solid will recover its original dimensions. When the load is removed.the recovery of the original dimensions of a deformed body when the load is removed is known as elastic behavior.

The limiting load beyond which the material no longer behaves elastically is the elastic limit. if the elastic limit is exceeded , the body will experience permanent set or deformation when the load is removed.

A body which is permanently deformed is said to have undergone plastic deformation.

For most materials, as long as the load does not exceed the
elastic limit, the deformation is proportional to the load. Thisrelationship is known as hooke's law. It is more frequently stated asstress. (2)

1.4: Brasses

Copper & zinc alloyed constitute brass, one of the commonest of alloys. Copper & zinc can be alloyed in any proportion, but not more than (40%) of copper is used in the common commercial copper-zinc alloys.

Brass can be cast directly into shape & rolled or drawn into sheets, tube, rods & wire.

It resists corrosion better than steel and finds a wide use for hydraulic fittings & pump linings & in places where prolonged exposure to moisture is necessary. Brass costs seven or eight times as much as mild steel. Brass is also a useful metal for bearings. If it is attempted to run a steel shaft in a steel bearing, the rubbing surfaces cut & tear each other. If, however a softer metal, such as brass, is used as a bearing metal against steel, a smooth surface is worn and, with light lubrication, cutting and tearing is not as likely to take place. The lattice structure of brass is face centered cubic. (4)

1.5: Bronze

Copper &tin also can be alloyed in many proportions. The properties of bronze, as copper-tin alloys are called.

Bronze can be cast into shape or rolled into wire, rods, and sheets. It resists corrosion even better than brass & is a more expensive alloy than brass. Its uses are, in general, the same. The term brass & bronze are somewhat loosely used in practice, either term being frequently used to denote any yellow metal containing copper in large proportion. The lattice structure of bronze is face centered cubic. (4)

1.6: Steel

Steel is possibly the most widely used material for machine elements because of its properties of high strength, high stiffness, durability, and relative ease of fabrication.The term steel refers to an alloy of iron, carbon, manganese, and one or more other significant elements; carbon has a very strong effect on the strength, hardness, and ductility of any steel alloy.

The other elements affect hardenability, toughness, corrosionresistance, machinability, and strength retention at high temperatures. The primary alloying elements present in the various alloy steels are sulfur, phosphorus, silicon, nickel, chromium, molybdenum, and vanadium.

As carbon content increases, strength & hardness also increase under the same conditions of processing & heat treatment.

Since ductility decreases with increasing carbon content, selecting suitable steel involves some compromise between strength & ductility.(7)

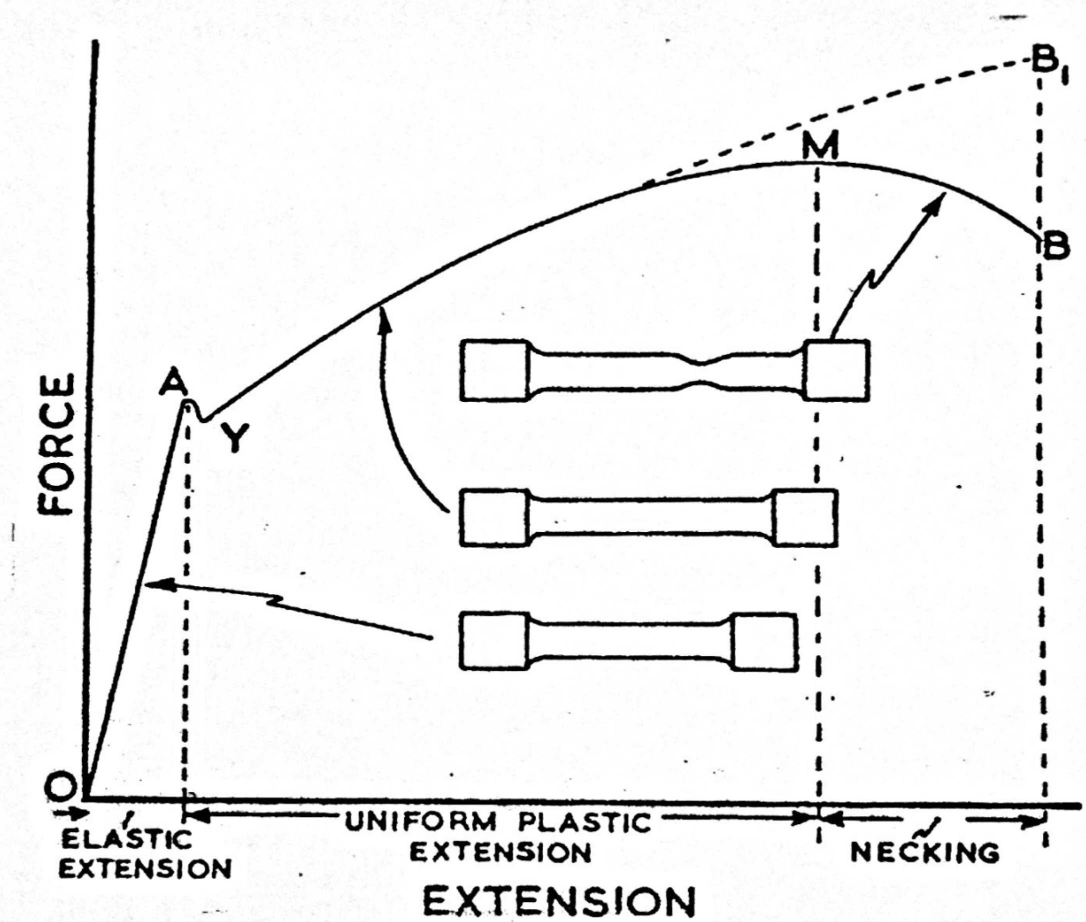
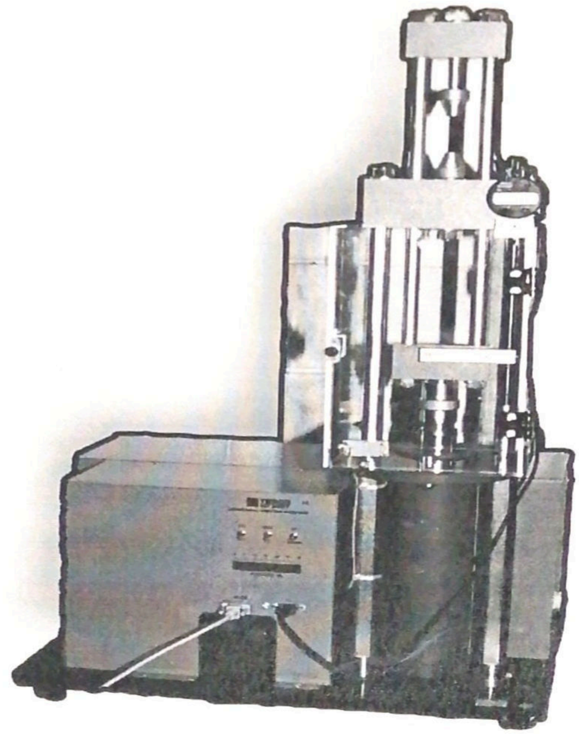

B1
M
B
A
Y
FORCE
O
ELASTIC
EXTENSION
UNIFORM PLASTIC
EXTENSION
NECKING
EXTENSION

Figure (1.1)



Figure(1.2)

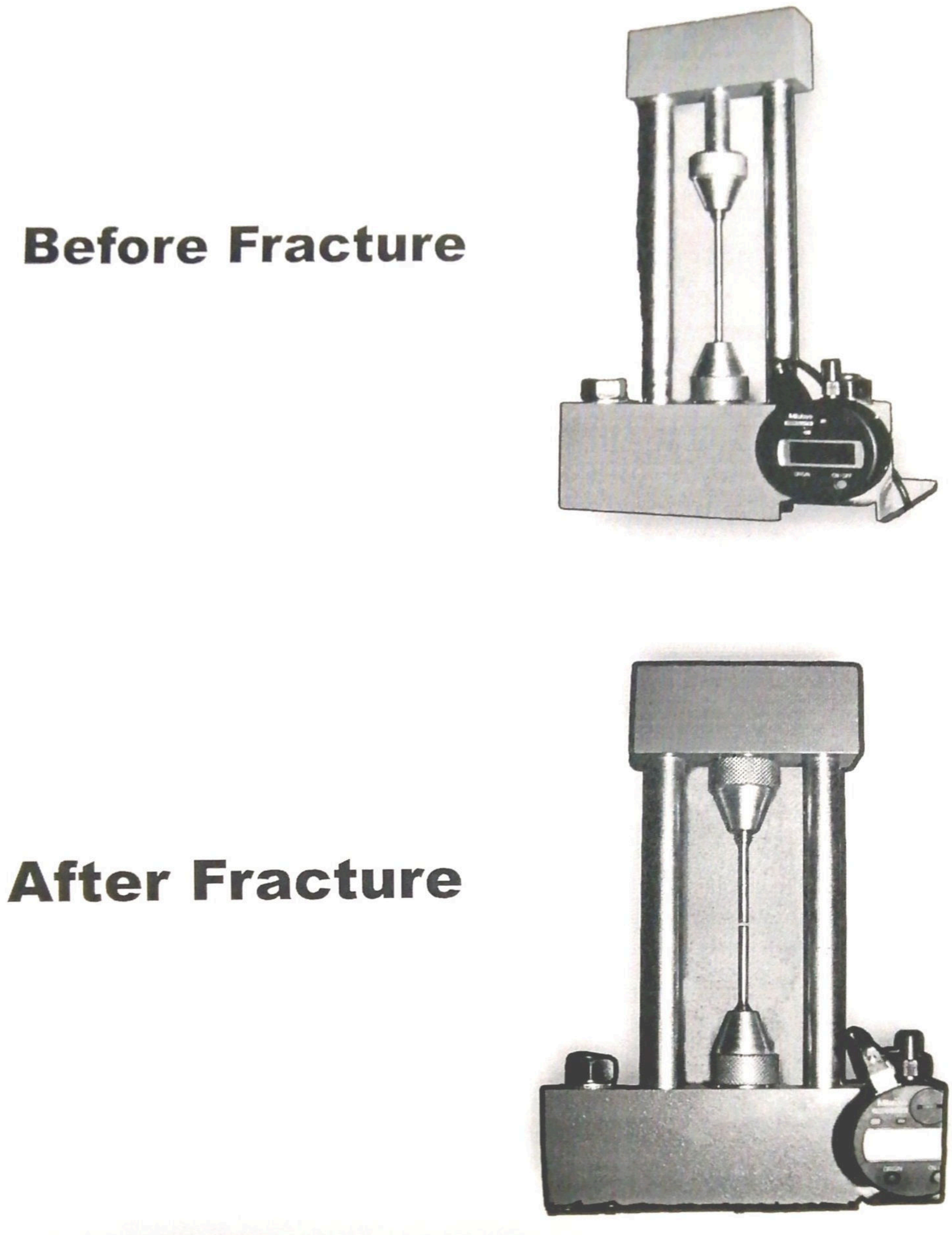


Figure (1.3)

(a) Before Testing

(b) After Testing

Figure (1.4)

(a) Before Testing

(b) After Testing

Chapter 2
Experimental Work Part

2.1: Objectives

The aim of this project is to study and verify the effect of different rate of straining on the flow stress of three different materials.

2.2: Materials and instrument

The materials and instrument, which have been used, are:-

1- Tensile testing machine.
2- Test piece made from three different materials (steel, brass, and bronze).
3- Stop watch.

2.2.1: Tensile testing machine

Figure (4.2) shows a photograph of the equipment MT 3037 universal testing machine used to pull the two ends of the test piece to failure. The machine is especially designed for teaching purpose, and it is very easy to handle. The machine is fully automatic and the power is generated by a motor driven hydraulic cylinder .It can be controlled both manually or by computer. The speed of the cylinder can be manually adjusted to the requirement of the test. The power is transferred extremely smoothly and with constant speed, thus givingbest possible test results. The power as well as the extension will be displayed on the monitor both as digital values and as bar diagrams. After the test, a complete diagram is displayed both as table and as diagram can be printed out.

2.2.2: Test piece (Tensile test specimen)

Standard tensile test specimens were used. Each specimen has hexagonal cross — sectional ends. Therefore, the two ends were machined on the lathe to produce threaded ends to fit the screw of the jaws on the tensile test machine. Figure (4.4) shows three specimens used during the test, Ns which they are made from 3 different materials, namely steel, brass, bronze

2.2.3: Stop watch

Is used to record the time (t), which is used in calculated the testing speed (v) and strain rate ($\dot{\varepsilon}$)

2.3: Testing procedure:

Before starting any test, connections between tensile testing machine and the computer should be checked, then:

1- The test piece is inserted so that the threaded ends of the test piece are screwed into the jaws on the tensile test machine. Itis essential that the test piece be aligned correctly in the testing machine.

2- DL indicator has been set to zero.

3- The middle control switch has been put to " pc " and then in personnel computer, measurement is clicked and (0 - 30) kNhas been chosen.

4- The plastic safety door is closed.

5- The testing speed can be adjusted by turning the speed adjustment valve. Which is located under the instrument panel. The valve is sensitive and kept at the same position for three different materials specimen.

6- The experiment is started by clicking the start button on the screen of the computer. The machine starts and the cylindermoves slowly upwards. Meanwhile, the measuring values are stored in a table.

7- When the test piece is broken, the power went down very quickly and the machine stopped automatically.

8- After the test is finished, " table " is clicked and the complete table is shown on the screen of the computer. By clicking thetable icon, the measuring values are transferred to a diagram.

9- Repeat the above procedure, after changing test speed by turning the speed adjustment valve.

Tables (2.1) to (2.6) show the results of the experimental work.

MATERIAL: BRONZE
DIAMETRE: 5 (mm)
LENGTH: 75 (mm)
STRAIN RATE: 0.0018 (1/sec)

TABLE (2-1)

NO	F(KN)	DL(mm)	strain	Stress(Map)
1	0	0	0	0
2	2.4	0.08	0.0001067	122.2929936
3	2.7	0.12	0.0001600	137.5796178
4	3.0	0.15	0.0002000	152.8662420
5	3.3	0.18	0.0002400	168.1528662
6	3.6	0.21	0.0002800	183.4394904
7	4.0	0.24	0.0003200	203.8216561
8	4.4	0.29	0.0003887	224.2038217
9	5.0	0.33	0.0004400	254.7770701
10	5.4	0.38	0.0005067	275.1592357
11	5.8	0.41	0.0005467	295.5414013
12	6.2	0.45	0.0006000	315.9235669
13	6.7	0.50	0.0006667	341.4012739
14	7.0	0.55	0.0007333	356.6878981
15	7.4	0.60	0.0008000	377.0700637
16	7.6	0.65	0.0008667	387.2611465
17	7.7	0.71	0.0009467	392.3566879
18	7.7	0.76	0.0010333	392.3566879
19	7.7	0.82	0.0010933	392.3566879
20	7.6	0.87	0.0011600	387.2611465
21	7.6	0.93	0.0012400	387.2611465
22	7.6	0.99	0.0013200	387.2611465
23	7.5	1.05	0.0014000	382.1656051
24	7.5	1.11	0.0014800	382.1656051
25	7.5	1.17	0.0015600	382.1656051

MATERIAL: BRONZE
DIAMETRE: 5 (mm)
LENGTH: 75 (mm)
STRAIN RATE: .00125 (1/sec)

TABLE (2-2)

NO	F(KN)	DL(mm)	strain	Stress(Map)
1	0.0	0.00	0.0	0.0
2	2.2	0.08	0.001066667	112.1019108
3	2.9	0.14	0.001866667	147.7707006
4	3.6	0.19	0.002533333	183.4394904
5	4.5	0.27	0.0036	229.2993631
6	5.4	0.34	0.004533333	275.1592357
7	6.1	0.43	0.005733333	310.8280255
8	6.5	0.51	0.0068	331.2101911
9	6.5	0.61	0.008133333	331.2101911
10	6.5	0.71	0.009466667	331.2101911
11	6.4	0.81	0.0108	326.1146497
12	6.4	0.92	0.012266667	326.1146497
13	6.3	1.02	0.0136	321.0191083
14	6.2	1.12	0.014933333	315.9235669
15	6.2	1.20	0.016	315.9235669
16	6.0	1.30	0.017333333	305.7324841
17	5.9	1.41	0.0188	300.6369427
18	5.7	1.52	0.020266667	290.4458599
19	5.5	1.64	0.021866667	280.2547771
20	5	1.75	0.023333333	254.7770701
21	4.3	1.89	0.0252	219.1082803

MATERIAL: BRASS
DIAMETRE: 5 (mm)
LENGTH: 75 (mm)
STRAIN RATE: 0.00125 (1/sec)

TABLE (2-3)

NO	F(KN)	DL(mm)	strain	Stress(Map)
1	0.0	0	0	0
2	2.4	0.09	0.00012	122.2929936
3	2.9	0.14	0.000186667	147.7707006
4	3.3	0.18	0.00024	168.1528662
5	3.7	0.22	0.000293333	188.5350318
6	4.2	0.27	0.00036	214.0127389
7	4.8	0.33	0.00044	244.5859873
8	5.4	0.39	0.00052	275.1592357
9	5.9	0.45	0.0006	300.6369427
10	6.4	0.52	0.000693333	326.1146497
11	6.6	0.57	0.00076	336.3057325
12	6.9	0.63	0.00084	351.5923567
13	7.1	0.71	0.000946667	361.7834395
14	7.2	0.78	0.00104	366.8789809
15	7.4	0.85	0.001133333	377.0700637
16	7.5	0.93	0.00124	382.1656051
17	7.5	1	0.001333333	382.1656051
18	7.6	1.07	0.001426667	387.2611465
19	7.7	1.15	0.001533333	392.3566879

MATERIAL: BRASS
DIAMETRE: 5 (mm)
LENGTH: 75 (mm)
STRAIN RATE: 0.0018 (1/sec)

TABLE (2-4)

NO	F(KN)	DL(mm)	strain	Stress(Map)
1	0	0	0	0
2	2.2	0.02	0.000266667	112.1019108
3	3.5	0.08	0.001066667	178.343949
4	4.5	0.14	0.001866667	229.2993631
5	5	0.2	0.002666667	254.7770701
6	5.4	0.25	0.003333333	275.1592357
7	5.9	0.3	0.004	300.6369427
8	6.4	0.35	0.004666667	326.1146497
9	6.9	0.42	0.0056	351.5923567
10	7.3	0.48	0.0064	371.9745223
11	7.6	0.55	0.007333333	387.2511465
12	7.8	0.62	0.008266667	397.4522293
13	8.1	0.69	0.0092	412.7388535
14	8.2	0.76	0.010133333	417.8343949
15	8.2	0.81	0.0108	417.8343949
16	8.3	0.89	0.011866667	422.9299363
17	8.4	0.96	0.0128	428.0254777
18	8.4	1.04	0.013866667	428.0254777
19	8.5	1.11	0.0148	433.1210191
20	8.5	1.19	0.015866667	433.1210191
21	8.6	1.26	0.0168	438.2165605
22	8.7	1.34	0.017866667	443.3121019
23	8.7	1.42	0.018933333	443.3121019
24	8.8	1.5	0.02	448.4076433
25	8.8	1.57	0.020933333	448.4076433

MATERIAL: STEEL
DIAMETRE: 5 (mm)
LENGTH: 75 (mm)
STRAIN RATE: 0.00125 (1/sec)

TABLE (2-5)

NO	F(KN)	DL(mm)	strain	Stress(Map)
1	0	0	0	0
2	3	0.09	0.00012	152.866242
3	3.3	0.11	0.000146667	168.1528662
4	3.8	0.15	0.0002	193.6305732
5	4.5	0.2	0.000266667	229.2993631
6	5.4	0.25	0.000333333	275.1592357
7	6.3	0.31	0.000413333	321.0191083
8	7.2	0.36	0.000048	366.8789809
9	8.1	0.41	0.000546667	412.7388535
10	9	0.46	0.000613333	458.5987261
11	9.9	0.51	0.00068	504.4585987
12	10.6	0.56	0.000746667	540.1273885
13	11.2	0.61	0.000813333	570.7006369
14	11.5	0.67	0.000893333	585.9872611
15	11.7	0.73	0.000973333	596.1783439
16	11.8	0.79	0.001053333	601.2738854
17	11.8	0.83	0.001106667	601.2738854
18	11.8	0.89	0.001186667	601.2738854
19	11.9	0.95	0.001266667	606.3694268
20	11.9	1.02	0.00136	606.3694268
21	11.9	1.08	0.00144	606.3694268
22	11.9	1.14	0.00152	606.3694268
23	11.9	1.21	0.001613333	606.3694268
24	12	1.28	0.001706667	611.4649682
25	12	1.34	0.001786667	611.4649682

MATERIAL: STEEL
DIAMETRE: 5 (mm)
LENGTH: 75 (mm)
STRAIN RATE: 0.0018 (1/sec)

TABLE (2-6)

NO	F(KN)	DL(mm)	Strain	Stress(Map)
1	0	0	0	0
2	3.6	0.1	0.000133	183.4394904
3	4.6	0.16	0.000213	234.3949045
4	5.9	0.23	0.000307	300.6369427
5	7.3	0.31	0.000413	371.9745223
6	8.6	0.38	0.000507	438.2165605
7	10	0.45	0.0006	509.5541401
8	11.3	0.52	0.000693	575.7961783
9	12.2	0.6	0.0008	621.656051
10	12.5	0.69	0.00092	636.9426752
11	12.6	0.79	0.001053	642.0382166
12	12.7	0.89	0.00187	647.133758
13	12.7	1	0.001333	647.133758
14	12.8	1.07	0.001427	652.2292994
15	12.8	1.17	0.00156	652.2292994
16	12.8	1.28	0.001707	652.2292994
17	12.8	1.39	0.001853	652.2292994
18	12.9	1.5	0.002	657.3248408
19	12.9	1.61	0.002147	657.3248408
20	12.9	1.72	0.002293	657.3248408
21	13	1.83	0.00244	662.4203822
22	13	1.94	0.002587	662.4203822
23	13	2.06	0.002747	662.4203822
24	13	2.18	0.002907	662.4203822
25	13.1	2.3	0.003067	667.5159236

Chapter 3
Experimental Results and Discussion

3.1 Experimental Results

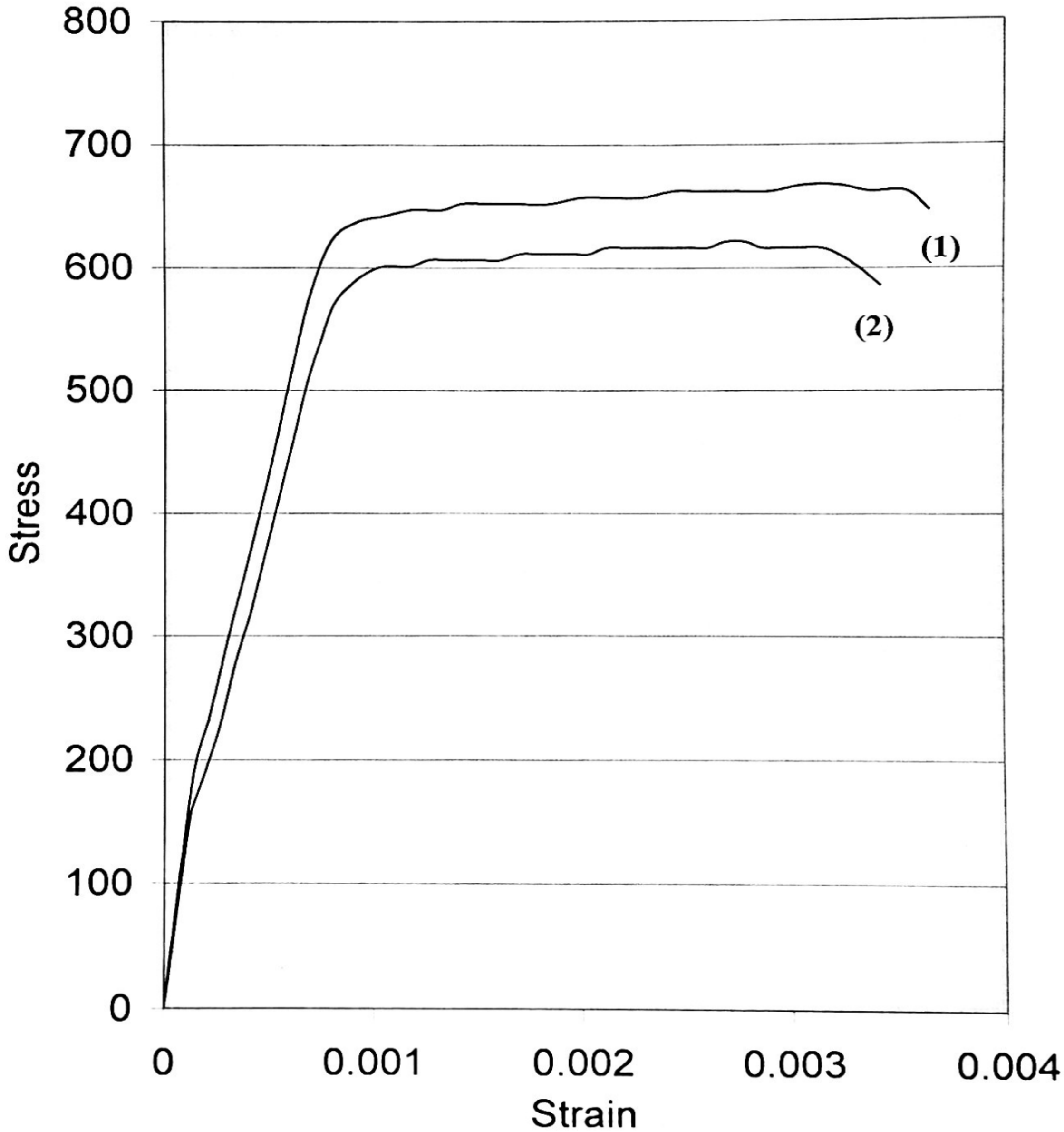
As it is mentioned perilously in chapter (2) tensile test were carried out for three different material test pieces namely made from (steel, brass, bronze). Two tensile tests were carried for each test piece material, firstly at slow strain rate of (0.0018 sec^{-1}) and secondly at faster strain rate of (0.00125sec^{-1}).
From these tests, reading of load-extension and load-extensiondiagram had been recorded by the aid of personnel computer.

The results of tests were tabulated in tables (2-1 to 2-6). It is necessary to mention, that all tests were carried out at room temperature.

3.2 Discussion of experimental results

From the results obtained, figures showing stress-strain diagram are plotted. Figure (3-1) shows stress-strain diagram for two steel test pieces, one pulled at strain rate of (0.0018sec^{-1}) and the other at strain rate of (0.00125sec^{-1}).
It can be noted that, the test piece pulled at slower strain rate achieved higher rates of stress and strain. This is due to strain hardening. Also it is easy to see that specimen tested at faster strainrate is reached failure pre-maturely. This may be attributed to in-homogeneity of structure at the middle of specimen. Figures (3-2) and (3-3) illustrate the stress-strain diagrams for bronze and brasstest pieces, respectively. It is easy to see that both figures have the same pattern, and diagrams indicate that at slower strain rate of (0.00125sec^{-1}) the results tend to have higher levels of stress and strain. Also, this is due to strain hardening. Figures (3-4) and (3-5)
Show the comparison of stress-strain diagrams for the three different materials of the specimens. For slower, and faster rate of deformation. It can be observe easily that steel reached highest levels of stress and strain, while bronze took the lowest with brass in between, and this is expectable due to the nature and properties of these materials.

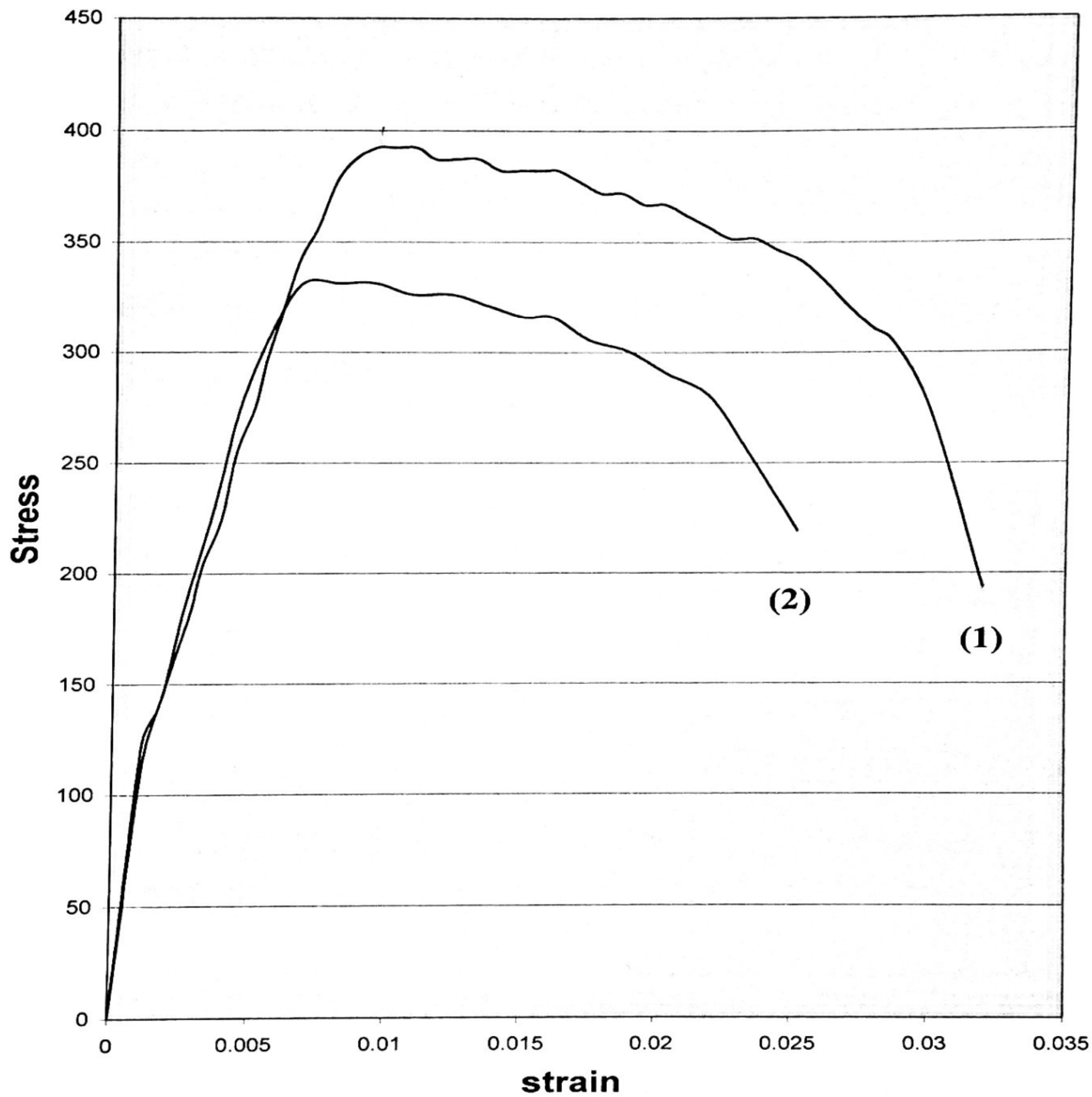
(1) Strain rate 0.0018 (sec^{-1}).
(2) Strain rate 0.00125 (sec^{-1}).



STRESS - STRAIN DIAGRAM
FOR STEEL

Figure (3 – 1)

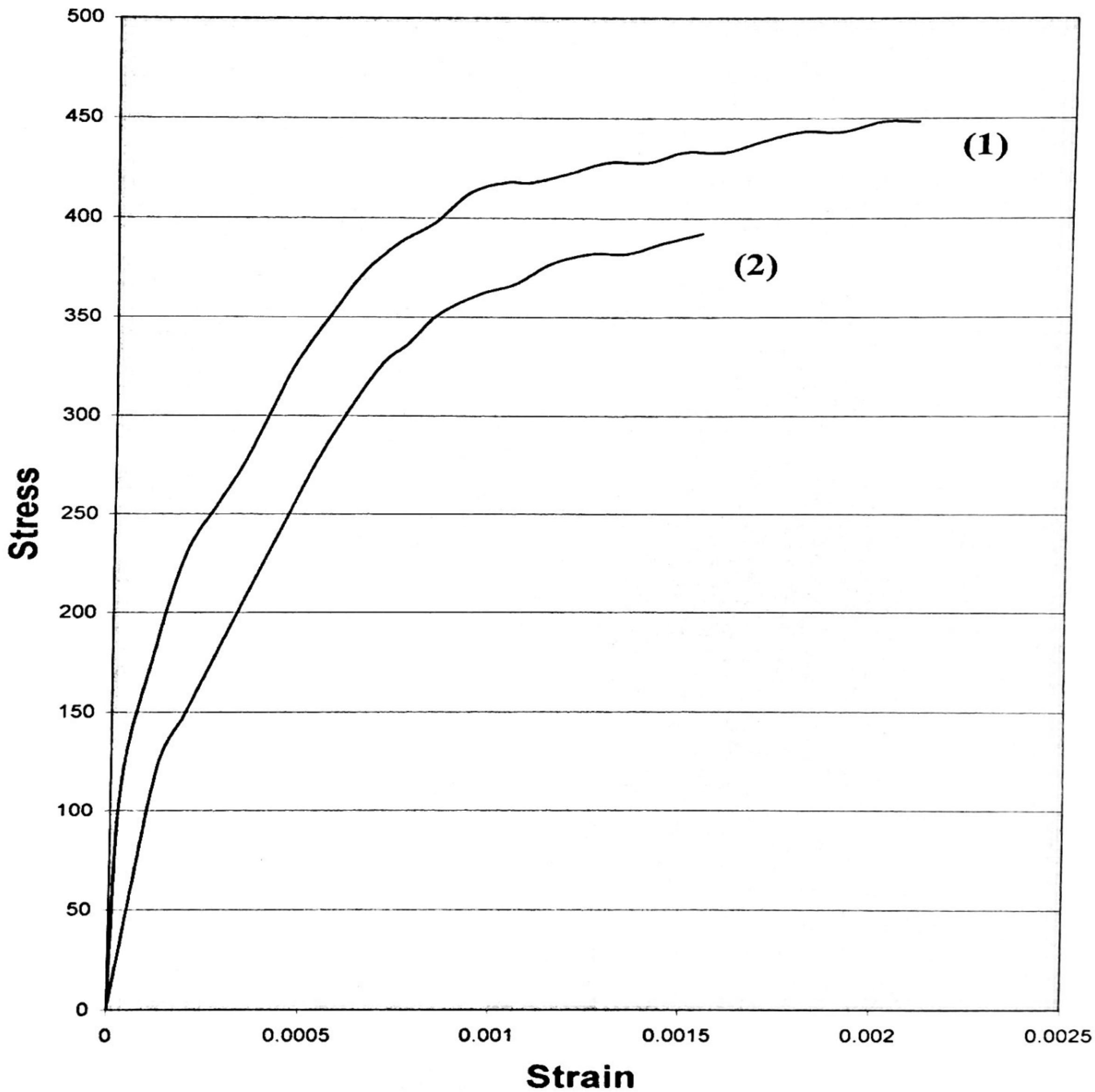
(1) Strain rate 0.0018 (sec^{-1}).
(2) Strain rate 0.00125 (sec^{-1}).



STRESS - STRAIN DIAGRAM
FOR BRONZE

Figure (3 – 2)

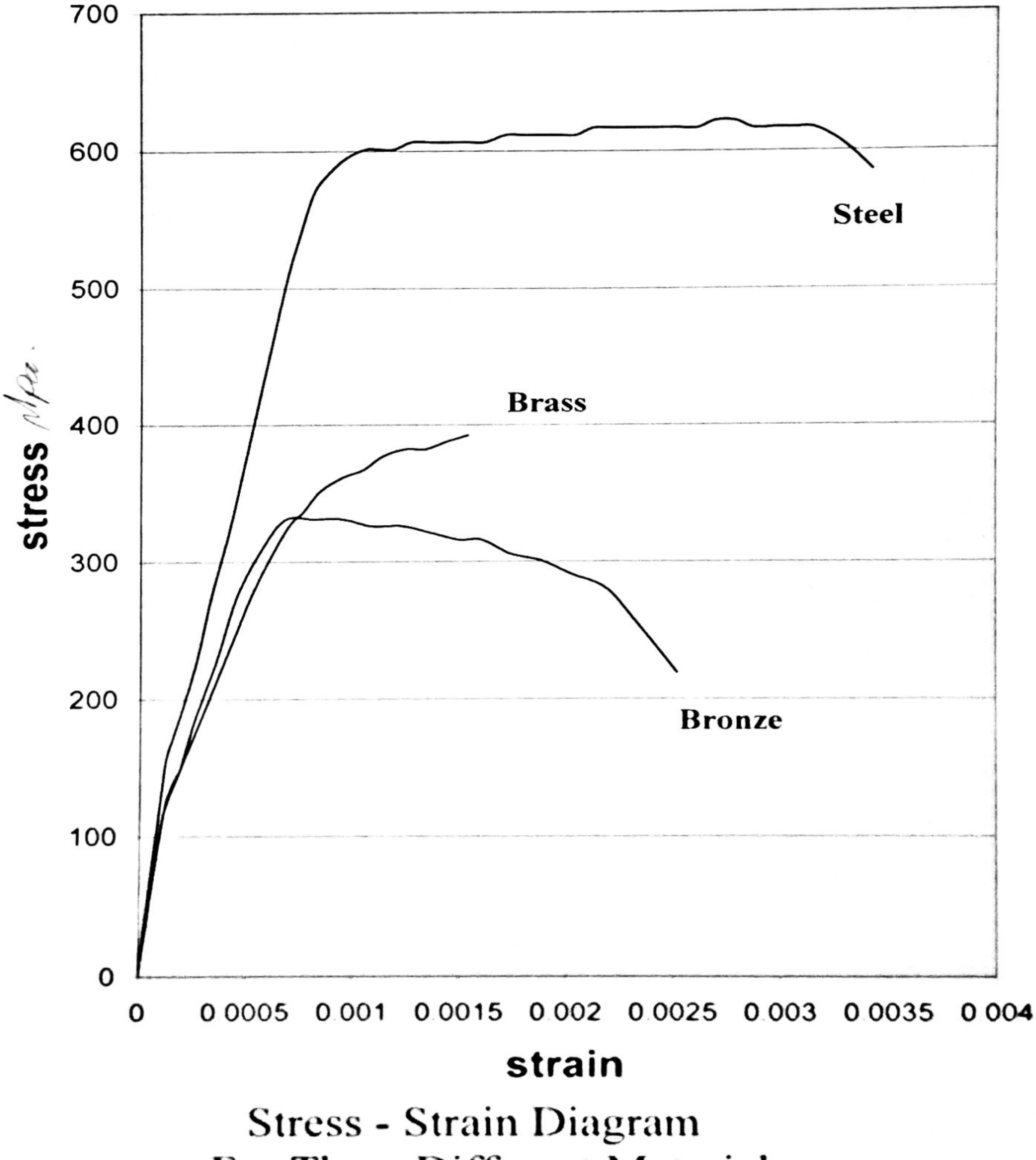
(1) Strain rate 0.0018 (sec^{-1}).
(2) Strain rate 0.00125 (sec^{-1}).



STRESS - STRAIN DIAGRAM
FOR brass

Figure (3 – 3)

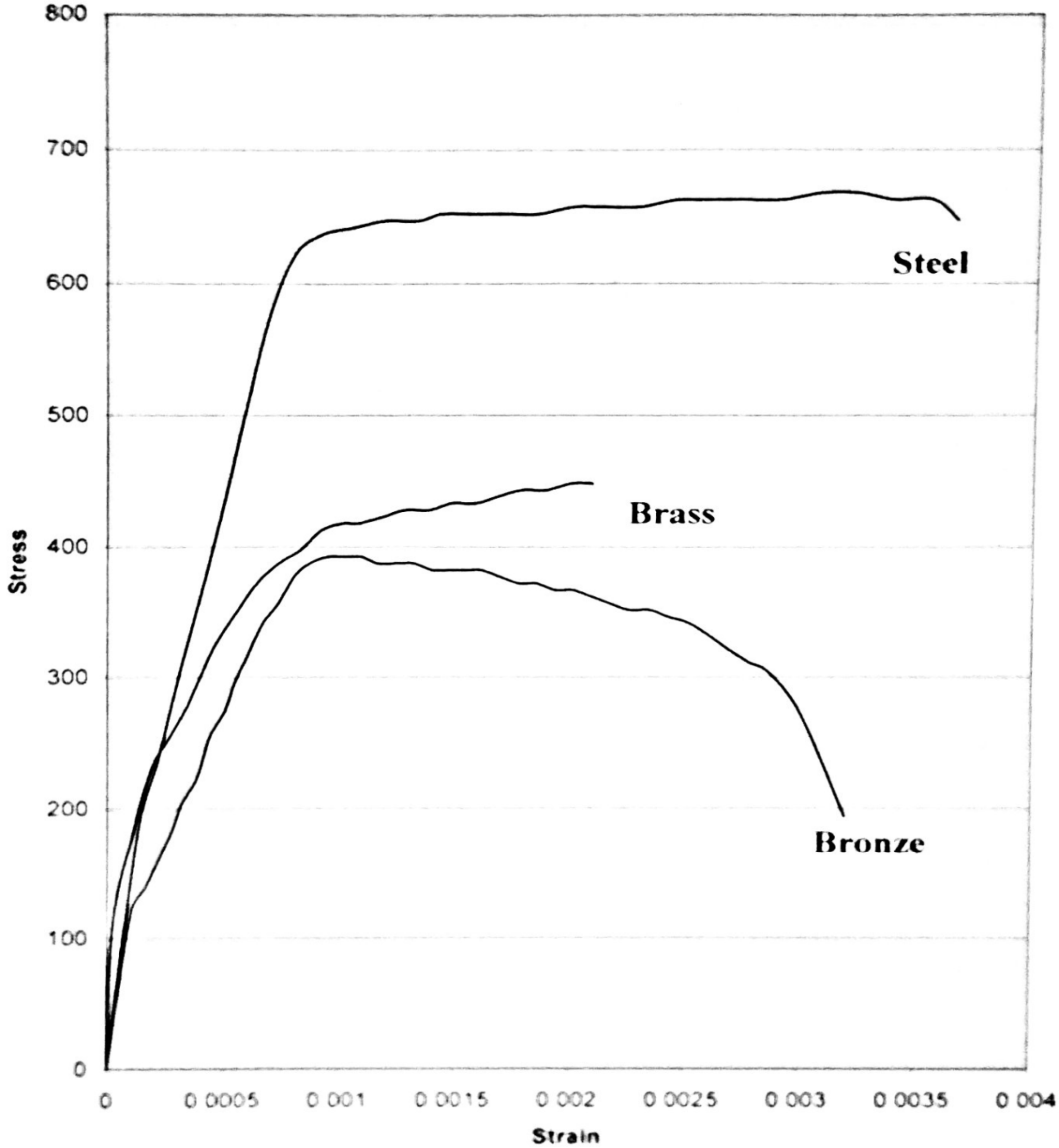
Strain rate 0.00125 (sec^{-1}).



Stress - Strain Diagram
For Three Different Materials

Figure (3 -4)

Strain rate 0.0018 (sec^{-1}).



Stress - Strain Diagram
For Three Different Materials

Figure (3 –5)

3.3 Conclusions

From the experimental results obtained during tensile testing, it's easy to conclude that:

1 - As the strain rate is raised the flow stress increased and the slop of the curve decreases for the three metals studied.

2- The pattern of stress-strain diagram for the three different materials and two-strain rate was as expected, the highest for steel, lowest for bronze and brass in between.

3- The ductility of the metal is increased by increased of strain rate.

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