The International Journal Of Engineering And Science (IJES)
||Volume||3 ||Issue|| 2||Pages|| 14-34||2014||
ISSN(e): 2319 – 1813 ISSN(p): 2319 – 1805

Mechanical Properties of Reinforcing Steel Rods Produced From Recycled Scraps

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-----ABSTRACT-----

This paper presents comparative experimental data on Mechanical Properties of Reinforced Steel produced from scrap and imported Reinforced Steel compared to International standard NO-432. Steel being part of everyday life of an individual, it is incumbent to study its physical properties so as to enable production of reliable steel bars. The Ultimate Tensile Strength (UTS), Yield Strength (YS), Breaking Strength (BS) and Hardness of steel bars manufactured from scraps and imported steel bars were investigated. Steel rods samples of 12mm and 16mm diameter were subjected to mechanical properties test using a universal testing machine. UTS, YS, BS and Hardness of the samples were obtained from the stress-strain curve plots obtained from the result data. It was observed that the locally produced steel from scrap were as good as the imported steel rods in terms of UTS, YS AND BS. Both the locally produced steel rod and imported steel rods conform with the standard in terms of yield stress but both have considerably low ultimate tensile stress compared to the standard values. The hardness values also point to the non-uniformity of the steel samples.

KEYWORDS: ***Reinforced*** *Steel bar, Mechanical Properties, Comparative Study, Scrap and Imported Steel bars*

Date of Submission: 06 February 2014 ⟺ Date of Acceptance: 15 February 2014

I. INTRODUCTION

Steel is an essential material for society and sustainable development; needed for people to satisfy their needs and aspirations. Steel is part of people's everyday lives, in both the developed and developing countries. It is used in providing transportation such as automobiles and railroads, building shelters from small housing to large multi-family dwellings, construction industries, delivering energy such as electricity and natural gas, supplying water with pumps and pipelines. Steel is an iron-based material containing low amounts of carbon and alloying elements that can be made into thousands of compositions with exacting properties to meet a wide range of needs. Steel is truly a versatile material. About twenty-six different elements are used in various proportions and combinations in the manufacture of both carbon and low alloy structural steels. Some are used because they impart specific properties to the steel when they alloy with it (i.e. dissolve in the iron), or when they combine with carbon, wholly or in part, to form compounds known as carbides. Others are used because they are beneficial in ridding the steel of impurities or rendering the impurities harmless. Still another group is used to counteract harmful oxides or gases in the steel (MIT, 1999). However, all finished steel bars for reinforced work are ensured sound, free from cracks, neatly rolled to the dimension and weight as specified. Several studies have being carried out on improving the mechanical properties of steel, (Yeon et al.,2007) did a study on methods to classify defects namely; crack, dark spot and sharp mark, of steel Bar Coil (BIC) with cylindrical shape. Each of these defect was qualified serious, that can harm quality of product relatively. Hence, it is important to detect these defects on the process of production. In their own study (Hamad K.et al., 2011), investigated the hardness variation over the different diameters of the same AISI 4140 bar. Measurements were taken on the two faces of the stock at equally spaced eight sectors and fifteen layers. Statistical and graphical analyses are performed to access the distribution of hardness measurements over the specified area. Hardness value is found to have a slight decrease trend as the diameter is reduced. However, an opposite behaviour is noticed regarding the sequence of the sector indicating a non-uniform distribution over the same area either on the same face or considering the corresponding sector on the other face (cross section) of the same material bar. (Amir and Morteza, 2013), did a study and presented comparative experimental data on the mechanical performance of steel and synthetic fibre-reinforced concrete under compression, tensile split and flexure. URW1050 steel fibre and HPP45 synthetic fibre, both with the same concrete design mix, was used to make cube specimens for a compression test, cylinders for a tensile split test and beam specimens for a flexural test. The experimental data demonstrated steel fibre reinforced concrete to be stronger in flexure at early stages, whilst both fibre reinforced concrete types displayed comparatively the same performance in compression, tensile splitting and 28-day flexural strength. In terms of post-crack control HPP45 was found to be preferable. This work is a comparative study of the mechanical properties namely; yield strength, ultimate tensile strength, percentage elongation and hardness, of locally made steel bars from scraps and imported steel bars has compared to the values provided by the International Standard NO-432, (Table 1).

Table 1: "Various grades of mild steel bars in accordance with standard IS: NO-432.

S/No	Types of nominal size of bars	Ultimate tensile stress N/mm^2 minimum	Yield stress N/mm^2	Elongation percent minimum
1.	Mild Steel Grade 1 or Grade 60			
	For bars up to 20mm	410	250	23
	For bars above 20mm up to 50mm	410	240	23
2.	Mild Steel Grade II or Grade 40			
	For bar up to 20mm	370	225	23
	For bars above 20mm up to 50mm	370	215	23
3.	Medium tensile steel grade 75			
	For bars up 16mm	540	350	20
	For bars above 16mm up to 32mm	540	340	20
	For bars above 32mm up to 50mm	510	330	20

Source: International Standard Organization (ISC) No. 432 part 1

II. METHODOLOGY

2.1 Materials

The samples used in this study were 12mm and 16mm diameter reinforced steel bars. These samples were obtained from two major sources namely: locally produced steel bars and imported steel bars. This is necessary for comparative investigation and analysis. Two specimens each of 1m length were collected on each of the diameter. The locally produced reinforced steel bars were obtained from three steel industries namely, Ife Iron and Steel (IFSM). Prism Steel rolling mill (PSM), Pheonix Steel Mill (PHSM). The imported steel samples (IM) were obtained from two different companies. A total of sixteen specimens (including imported steel) mechanical properties which includes yield strength, ultimate tensile strength, percentage elongation and hardness were investigated.

2.2 PHYSICAL REQUIREMENT

All finished steel bars for reinforced work were neatly rolled to the dimension and weighted as specified and are free from defects.

STEEL TESTING

2.3.1ULTIMATE TENSILE STRENGTH:

This test helps in determining the maximum stress that a material can withstand while being stretched or pulled before necking, which is when the specimen's cross-section starts to significantly contract.

2.3.2 YIELD STRENGTH:

Yield strength is the lowest stress that produces a permanent deformation in a material. In some materials, like aluminum alloys, the point of yielding is hard to define. Thus it is usually given as the stress causing 0.2% plastic strain. This is called a 0.2% proof stress.

2.3.3 ELONGATION:

The elongation is the increase in length of the gauge length, expressed as a percentage of the original length. In reporting elongation values, give both the percentage increase and the original gauge length.

2.4 Tensile test results were analyzed using the following equations:

Ultimate Tensile Strength, UTS

$$UTS = \frac{Maximum\ Load\ (ML)}{Norminal\ Area\ (A_1)} \qquad \ldots 1$$

Yield Strength, YS

$$YS = \frac{Yield\ Load\ (YL)}{Norminal\ Area\ (A_1)} \qquad \ldots 2$$

Breaking Strength, BS

$$BS = \frac{Breaking\ Load\ (BL)}{Norminal\ Area\ (A_1)} \qquad \ldots 3$$

2.5 Detailed Procedure of Tensile Test

The samples were turned into standard configuration using the lathe machine. Steel are cut into required length of the machine acceptability. An Instron universal Testing Machine at Engineering Materials Development Institute, Ondo Road, Akure was used in this regard. The resulting tension, load, stress and strain were measured, recorded, tabulated and plotted with the help of a control system and its associated software.

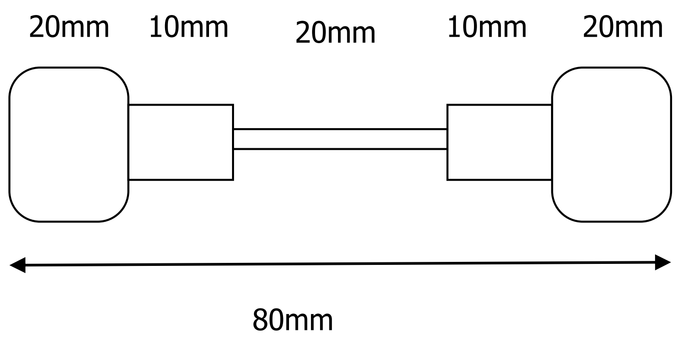

Fig 1: A Sample of the Tested Steel

2.6 Detailed Procedure of Hardness Test

The correct hardness values are beneficial for material selection and design together with material development for higher performance. Moreover, the hardness values can be used for estimating other related mechanical properties of the materials. The bottom of form shaped specimen was grounded with grinding and polishing machines with application of water in order to view the structure very well in micro hardness testing machine. The specimen was screwed into the machine and viewed through a microscope lens and left for some minute before the reading was taken.

III. RESULTS AND DISCUSSION

Tables 2-17 shows the results of Tensile test and the stress-strain curve plots, from the stress-strain curves it was observed that all the steel samples have low region of proportionality, hence, the high ultimate tensile stress value with the exception of PSM 16, Figs. 11 and 13, having a high proportionality limit with the least UTS value of 13842 and 13913 respectively. IFSM 12 has the highest yield stress YS values, this is obvious from the pronounced yield point in Figs. 2 and 5. The hardness result on Table 19 has some variation to point to non-uniformity of constituent steel sample, (Hamad et al, 2011). The minimum standard hardness for reinforcing steel bars can be estimated as 13.48HRC (BS4449, 1997). The result shows that PSM 12mm with the highest carbon content of 0.416%C (Ponle et al, 2014) has hardness 290.0HRC while PSM 16mm with the least carbon content has a hardness value of 232.2HRC. The trend of hardness also shows that the higher the carbon content the higher the hardness. Carbon also has negative effect on properties such as reduction in area (as well as total elongation). The trend shows that %E (elongation) decreases as carbon content increases. PSM 12mm has carbon content 0.416%C, PSM 16mm 0.112%C, IFSM 12mm 0.32%C, IFSM 16mm 0.277%C, PHSM 12mm 0.334%C, PHSM 16mm 0.194%XC, IM 12mm 0.377%C, IM 16mm 0.244%C. (Ponle et al., 2014). Increasing the carbon content produces a material with higher strength and lower ductility. It was observed that the locally produced steel from scrap were as good as the imported steel rods in terms of UTS, YS AND BS. Both the locally produced steel rod and imported steel rods conform with the standard in terms of yield stress but both have considerably low ultimate tensile stress compared to the standard values. The hardness values also point to the non-uniformity of the steel samples.

Table 2: The Resulting Tension, Load, Stress and Strain Result, IFSM 1 12MM

	Length (mm)	Maximum load (N)	Tensile strain at maximum load (mm/mm)	Tensile stress of maximum Load (MPa)
1	36.71000	6040.30751	0.68107	295.68469
	Tensile strain at Yield (Zero Slope) (mm/mm)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile Stress at Break (Standard) (MPa)
1	0.11577	0.67648	122.65015	528.80347
	True stress at Break (Standard) (MPa)	Tensile extension at Yield (Zero slope) (mm)	Tensile extension at Break (Standard) (mm)	Energy at Yield (Zero Slope) (J)
1	886.52855	4.24984	24.83359	6.94453
	Energy at Break (Standard) (J)	Load at Yield (Zero Slope) (N)	Load at Break (Standard) (N0	Extension at Maximum Load (mm)
1	193.57452	2505.52241	10802.50591	25.000218
	Extension at Yield (Zero Slope) (mm)	Tensile extension at Maximum Load (mm)	True strain at Break (Standard) (mm/mm)	True strain at Maximum Load (mm/mm)
1	4.24984	25.00218	0.51670	0.51943
	True stress at Maximum Load (MPa)	True strain at Yield (Zero Slope) (mm/mm)	True stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)
1	497.06748	0.10954	136.84911	6416.80374
	Energy to X-Intercept at Modulus (E-modulus) (J)	X – Intercept at Modulus (E-modulus) (mm/mm)	Y-Intercept at Modulus (E-modulus) (MPa)	Final area (cm^2)
1	0.12402	0.02542	163.144430	0.03142
	Final diameter (mm)	Final Length (mm)	Diameter (mm)	Final linear density (tex)
1	2.00000	100.0000	5.10000	
	Extension at Break (standard)(mm)			
1	24.83359			

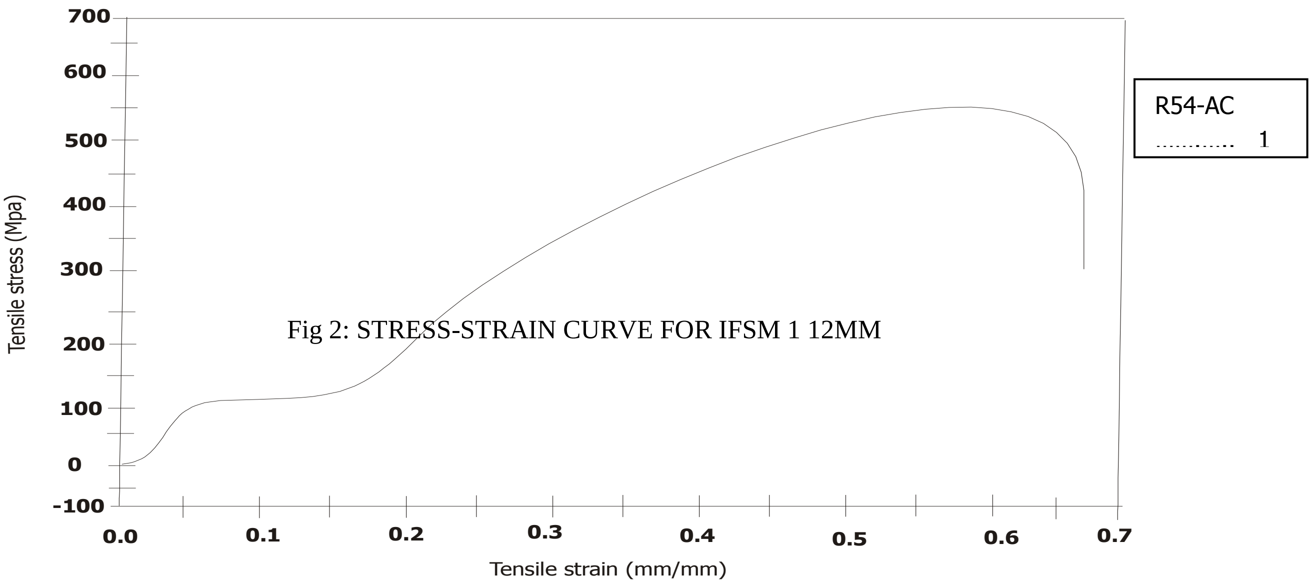

Fig 2: STRESS-STRAIN CURVE FOR IFSM 1 12MM

Table 3: The Resulting Tension, Load, Stress and Strain Result, IFSM 1 16MM

	Length (mm)	Maximum load (N)	Tensile strain at maximum load (mm/mm)	Tensile stress of maximum Load (MPa)
1	36.71000	5509.74123	0.57474	269.71243

	Tensile strain at Yield (Zero Slope) (mm/mm)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile Stress at Break (Standard) (MPa)
1	0.45855	0.57206	594.50885	491.44727

	True stress at Break (Standard) (MPa)	Tensile extension at Yield (Zero slope) (mm)	Tensile extension at Break (Standard) (mm)	Energy at Yield (Zero Slope) (J)
1	772.58442	16.83343	21.00031	127.21014

	Energy at Break (Standard) (J)	Load at Yield (Zero Slope) (N)	Load at Break (Standard) (N0	Extension at Maximum Load (mm)
1	175.05795	12144.74961	10039.38615	21.09875

	Extension at Yield (Zero Slope) (mm)	Tensile extension at Maximum Load (mm)	True strain at Break (Standard) (mm/mm)	True strain at Maximum Load (mm/mm)
1	8.99984	28.87453	0.57839	0.58029

	True stress at Maximum Load (MPa)	True strain at Yield (Zero Slope) (mm/mm)	True stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)
1	495.0210	0.21926	397.27176	5820.45364

	Energy to X-Intercept at Modulus (E-modulus) (J)	X – Intercept at Modulus (E-modulus) (mm/mm)	Y-Intercept at Modulus (E-modulus) (MPa)	Final area (cm^2)
1	0.11135	0.03062	-178.20988	0.03142

	Final diameter (mm)	Final Length (mm)	Diameter (mm)	Final linear density (tex)
1	2.00000	100.0000	5.10000	

	Extension at Break (standard)(mm)
1	28.75031

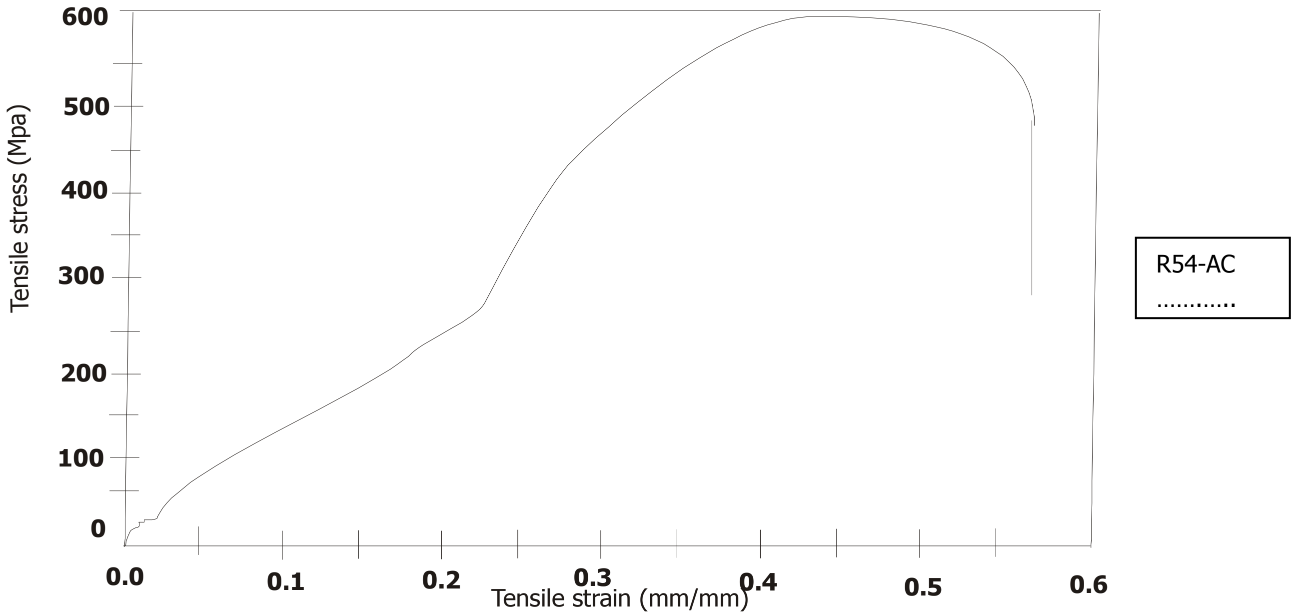

Fig 3: STRESS-STRAIN CURVE FOR IFSM 1 16MM

Table 4: The Resulting Tension, Load, Stress and Strain Result, IFSM 2 12MM

	Length (mm)	Maximum load (N)	Tensile strain at maximum load (mm/mm)	Tensile stress of maximum Load (MPa)
1	36.71000	5849.31336	0.78939	286.33514
	Tensile strain at Yield (Zero Slope) (mm/mm)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile Stress at Break (Standard) (MPa)
1	0.64469	0.78544	608.93018	498.40939
	True stress at Break (Standard) (MPa)	Tensile extension at Yield (Zero slope) (mm)	Tensile extension at Break (Standard) (mm)	Energy at Yield (Zero Slope) (J)
1	886.87912	23.66672	28.83343	156.40611
	Energy at Break (Standard) (J)	Load at Yield (Zero Slope) (N)	Load at Break (Standard) (N0	Extension at Maximum Load (mm)
1	217.56250	12439.35078	10181.60954	28.97843
	Extension at Yield (Zero Slope) (mm)	Tensile extension at Maximum Load (mm)	True strain at Break (Standard) (mm/mm)	True strain at Maximum Load (mm/mm)
1	16.83343	21.09875	0.45239	0.45409
	True stress at Maximum Load (MPa)	True strain at Yield (Zero Slope) (mm/mm)	True stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)
1	424.72726	0.37744	867.12194	2292.56725
	Energy to X-Intercept at Modulus (E-modulus) (J)	X – Intercept at Modulus (E-modulus) (mm/mm)	Y-Intercept at Modulus (E-modulus) (MPa)	Final area (cm^2)
1	---	-0.00460	10.55044	0.03142
	Final diameter (mm)	Final Length (mm)	Diameter (mm)	Final linear density (tex)
1	2.00000	100.0000	5.10000	
	Extension at Break (standard)(mm)			
1	21.00031			

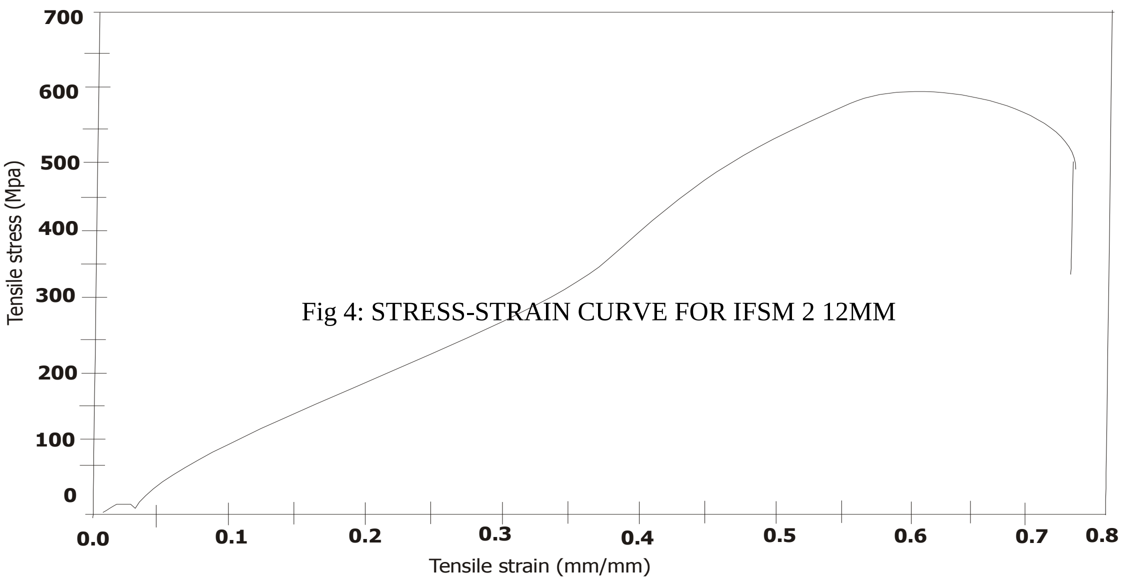

Fig 4: STRESS-STRAIN CURVE FOR IFSM 2 12MM

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Table 5: The Resulting Tension, Load, Stress and Strain Result, IFSM 2 16MM

	Length (mm)	Maximum load (N)	Tensile strain at maximum load (mm/mm)	Tensile stress of maximum Load (MPa)
1	36.71000	6008.61050	0.61987	294.13306
	Tensile strain at Yield (Zero Slope) (mm/mm)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile Stress at Break (Standard) (MPa)
1	0.50623	0.61746	607.75861	499.51596
	True stress at Break (Standard) (MPa)	Tensile extension at Yield (Zero slope) (mm)	Tensile extension at Break (Standard) (mm)	Energy at Yield (Zero Slope) (J)
1	807.94591	18.58359	22.66687	134.16316
	Energy at Break (Standard) (J)	Load at Yield (Zero Slope) (N)	Load at Break (Standard) (N0	Extension at Maximum Load (mm)
1	182.31182	12415.41803	10204.21460	22.75531
	Extension at Yield (Zero Slope) (mm)	Tensile extension at Maximum Load (mm)	True strain at Break (Standard) (mm/mm)	True strain at Maximum Load (mm/mm)
1	23.66672	28.97843	0.57966	0.58187
	True stress at Maximum Load (MPa)	True strain at Yield (Zero Slope) (mm/mm)	True stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)
1	512.36468	0.49755	1001.50376	1833.63876
	Energy to X-Intercept at Modulus (E-modulus) (J)	X – Intercept at Modulus (E-modulus) (mm/mm)	Y-Intercept at Modulus (E-modulus) (MPa)	Final area (cm^2)
1	0.09499	0.02074	-38.02723	0.03142
	Final diameter (mm)	Final Length (mm)	Diameter (mm)	Final linear density (tex)
1	2.00000	100.0000	5.10000	
	Extension at Break (standard)(mm)			
1	28.83343			

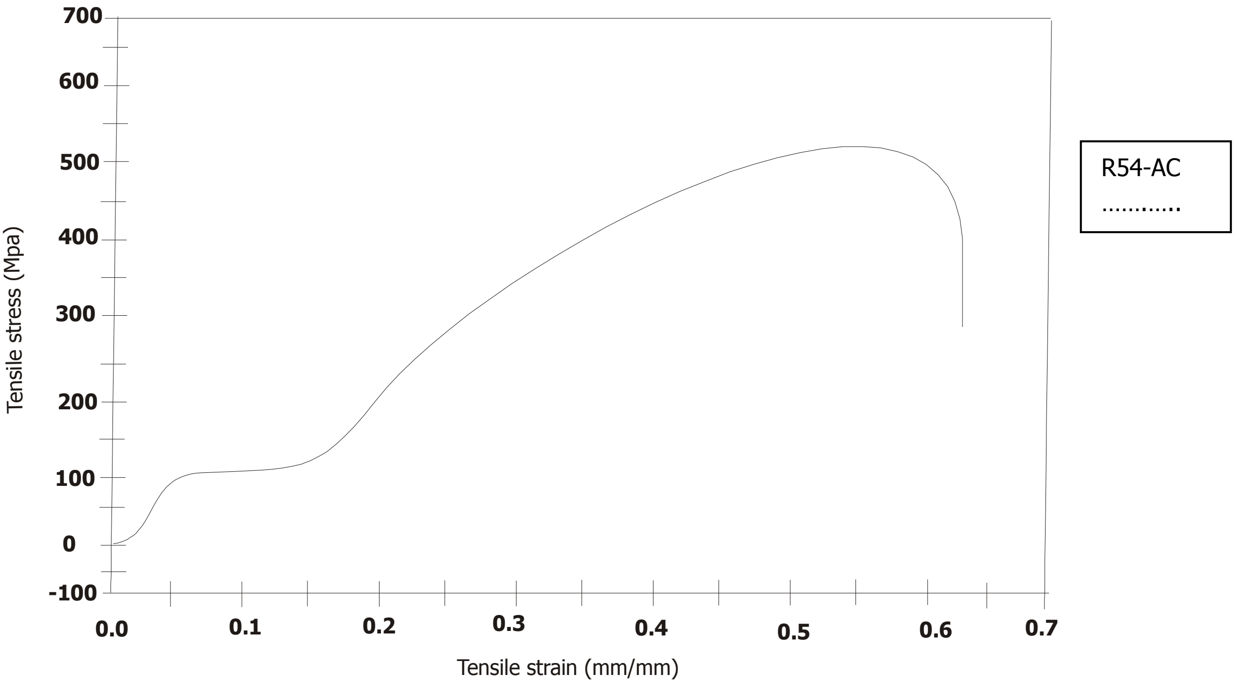

Fig 5: STRESS-STRAIN CURVE FOR IFSM 2 16MM

Table 6: The Resulting Tension, Load, Stress and Strain Result, PHSM 1 12MM

	Length (mm)	Maximum load (N)	Tensile strain at maximum load (mm/mm)	Tensile stress of maximum Load (MPa)
1	36.71000	5669.26338	0.62130	277.52136
	Tensile strain at Yield (Zero Slope) (mm/mm)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile Stress at Break (Standard) (MPa)
1	0.49033	0.61746	592.80420	470.98367
	True stress at Break (Standard) (MPa)	Tensile extension at Yield (Zero slope) (mm)	Tensile extension at Break (Standard) (mm)	Energy at Yield (Zero Slope) (J)
1	761.79614	18.00015	22.66687	125.56505
	Energy at Break (Standard) (J)	Load at Yield (Zero Slope) (N)	Load at Break (Standard) (N0	Extension at Maximum Load (mm)
1	178.53721	12109.92634	9621.35121	22.80781
	Extension at Yield (Zero Slope) (mm)	Tensile extension at Maximum Load (mm)	True strain at Break (Standard) (mm/mm)	True strain at Maximum Load (mm/mm)
1	18.58359	22.75531	0.48086	0.48234
	True stress at Maximum Load (MPa)	True strain at Yield (Zero Slope) (mm/mm)	True stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)
1	476.45636	0.40961	915.42238	6923.11401
	Energy to X-Intercept at Modulus (E-modulus) (J)	X – Intercept at Modulus (E-modulus) (mm/mm)	Y-Intercept at Modulus (E-modulus) (MPa)	Final area (cm^2)
1	0.11352	0.02856	-197.74364	0.03142
	Final diameter (mm)	Final Length (mm)	Diameter (mm)	Final linear density (tex)
1	2.00000	100.0000	5.10000	
	Extension at Break (standard)(mm)			
1	22.66687			

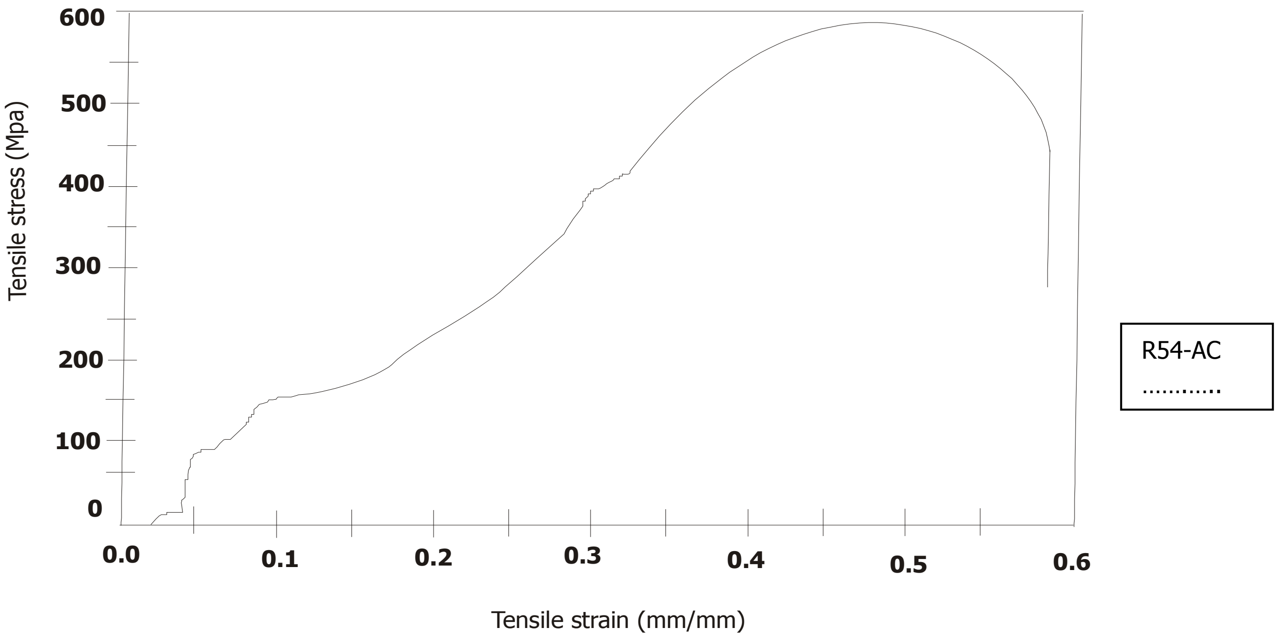

Fig 6: STRESS-STRAIN CURVE FOR PHSM 1 12MM

Table 7: The Resulting Tension, Load, Stress and Strain Result, PHSM 1 16MM

	Length (mm)	Maximum load (N)	Tensile strain at maximum load (mm/mm)	Tensile stress of maximum Load (MPa)
1	36.71000	5783.65251	0.68539	283.12091
	Tensile strain at Yield (Zero Slope) (mm/mm)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile Stress at Break (Standard) (MPa)
1	0.59021	0.68102	534.21344	470.92740
	True stress at Break (Standard) (MPa)	Tensile extension at Yield (Zero slope) (mm)	Tensile extension at Break (Standard) (mm)	Energy at Yield (Zero Slope) (J)
1	791.63922	21.66656	25.00031	122.34304
	Energy at Break (Standard) (J)	Load at Yield (Zero Slope) (N)	Load at Break (Standard) (N0	Extension at Maximum Load (mm)
1	157.76609	10913.02261	9620.20159	25.16078
	Extension at Yield (Zero Slope) (mm)	Tensile extension at Maximum Load (mm)	True strain at Break (Standard) (mm/mm)	True strain at Maximum Load (mm/mm)
1	18.00015	22.80781	0.48086	0.48323
	True stress at Maximum Load (MPa)	True strain at Yield (Zero Slope) (mm/mm)	True stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)
1	449.94451	0.39900	883.47614	6754.49371
	Energy to X-Intercept at Modulus (E-modulus) (J)	X – Intercept at Modulus (E-modulus) (mm/mm)	Y-Intercept at Modulus (E-modulus) (MPa)	Final area (cm^2)
1	0.11734	0.03173	-214.32712	0.03142
	Final diameter (mm)	Final Length (mm)	Diameter (mm)	Final linear density (tex)
1	2.00000	100.0000	5.10000	
	Extension at Break (standard)(mm)			
1	22.66687			

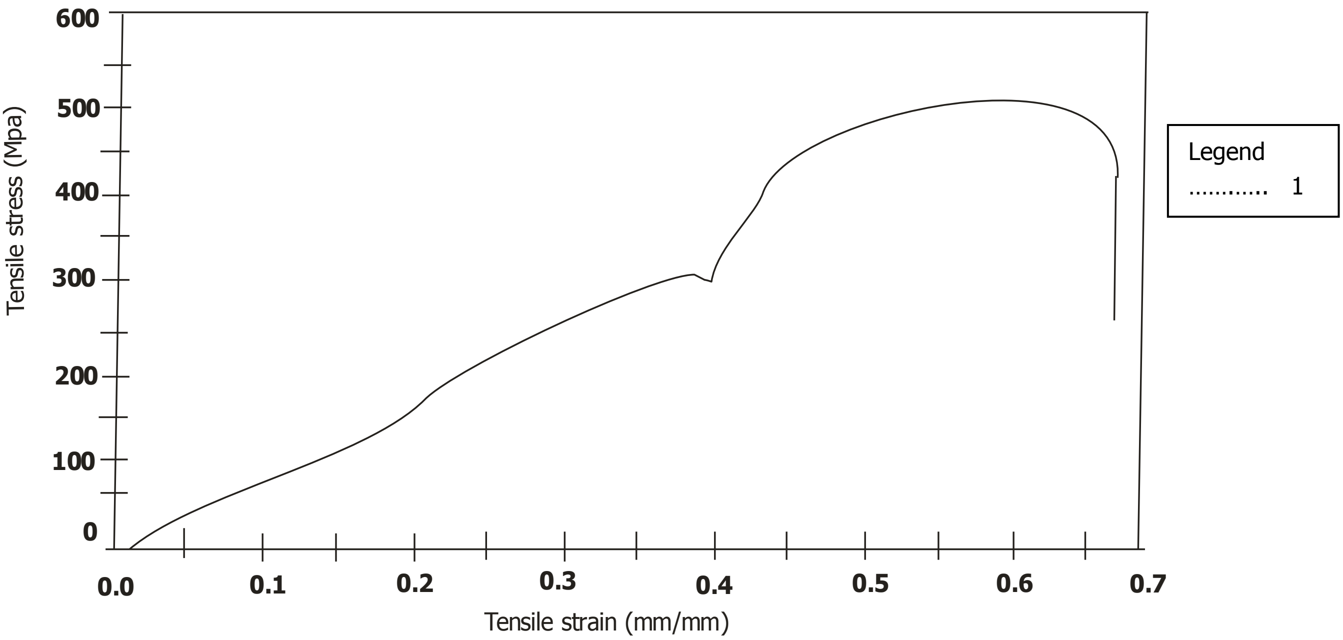

Fig 7: STRESS-STRAIN CURVE FOR PHSM 1 16MM

Table 8: The Resulting Tension, Load, Stress and Strain Result, PHSM 2 12MM

	Length (mm)	Maximum load (N)	Tensile strain at maximum load (mm/mm)	Tensile stress of maximum Load (MPa)
1	36.71000	5049.82434	0.65534	247.19862
	Tensile strain at Yield (Zero Slope) (mm/mm)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile Stress at Break (Standard) (MPa)
1	0.49487	0.65150	603.60114	431.21747
	True stress at Break (Standard) (MPa)	Tensile extension at Yield (Zero slope) (mm)	Tensile extension at Break (Standard) (mm)	Energy at Yield (Zero Slope) (J)
1	712.15744	18.16656	23.91672	130.21247
	Energy at Break (Standard) (J)	Load at Yield (Zero Slope) (N)	Load at Break (Standard) (N0	Extension at Maximum Load (mm)
1	195.15682	12330.48812	8808.99951	24.05765
	Extension at Yield (Zero Slope) (mm)	Tensile extension at Maximum Load (mm)	True strain at Break (Standard) (mm/mm)	True strain at Maximum Load (mm/mm)
1	21.66656	25.16078	0.51940	0.52200
	True stress at Maximum Load (MPa)	True strain at Yield (Zero Slope) (mm/mm)	True stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)
1	477.17003	0.46387	849.51088	824.47758
	Energy to X-Intercept at Modulus (E-modulus) (J)	X – Intercept at Modulus (E-modulus) (mm/mm)	Y-Intercept at Modulus (E-modulus) (MPa)	Final area (cm^2)
1	0.03551	0.02269	-18.70665	0.03142
	Final diameter (mm)	Final Length (mm)	Diameter (mm)	Final linear density (tex)
1	2.00000	100.0000	5.10000	
	Extension at Break (standard)(mm)			
1	25.00031			

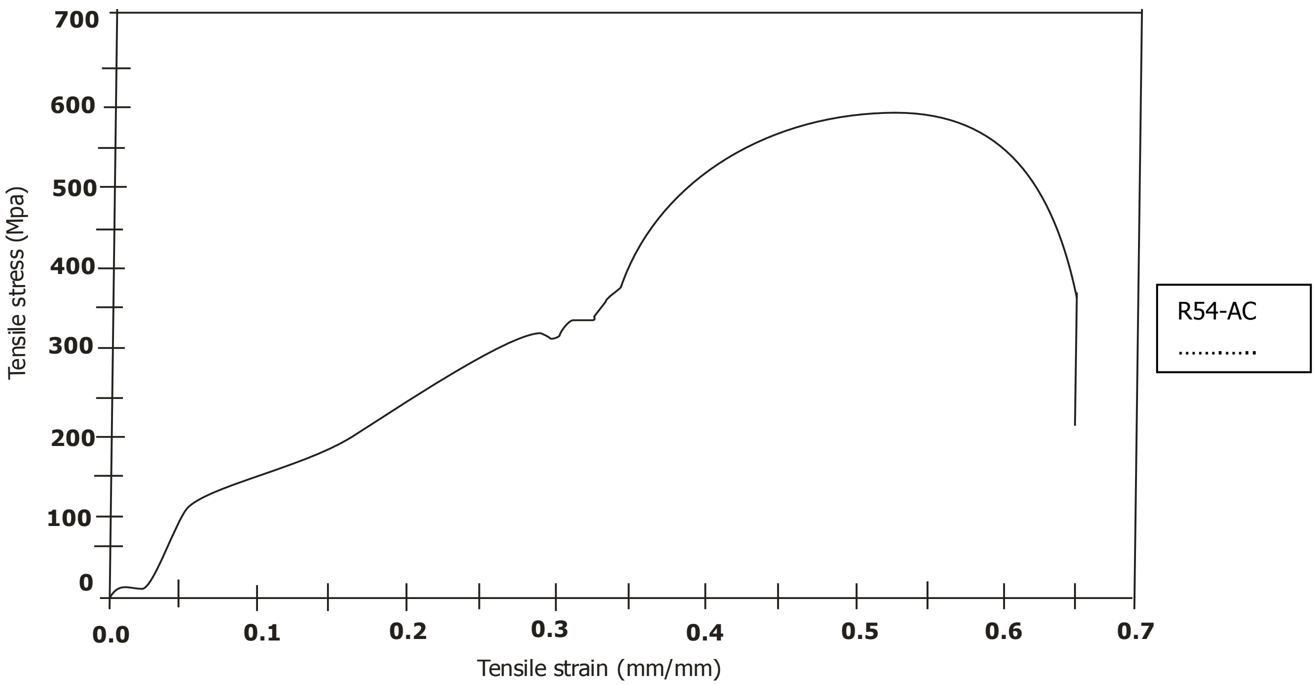

Fig 8: STRESS-STRAIN CURVE FOR PHSM 2 12MM

Table 9: The Resulting Tension, Load, Stress and Strain Result, PHSM 2 16MM

	Length (mm)	Maximum load (N)	Tensile strain at maximum load (mm/mm)	Tensile stress of maximum Load (MPa)
1	36.71000	5265.53467	0.89705	257.75806
	Tensile strain at Yield (Zero Slope) (mm/mm)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile Stress at Break (Standard) (MPa)
1	0.74684	0.89441	562.80115	426.20721
	True stress at Break (Standard) (MPa)	Tensile extension at Yield (Zero slope) (mm)	Tensile extension at Break (Standard) (mm)	Energy at Yield (Zero Slope) (J)
1	807.41065	27.41656	32.83374	167.03114
	Energy at Break (Standard) (J)	Load at Yield (Zero Slope) (N)	Load at Break (Standard) (N0	Extension at Maximum Load (mm)
1	225.32959	11497.01774	8706.64865	32.93062
	Extension at Yield (Zero Slope) (mm)	Tensile extension at Maximum Load (mm)	True strain at Break (Standard) (mm/mm)	True strain at Maximum Load (mm/mm)
1	18.16656	24.05765	0.50169	0.50401
	True stress at Maximum Load (MPa)	True strain at Yield (Zero Slope) (mm/mm)	True stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)
1	409.19858	0.40204	902.30326	6915.02609
	Energy to X-Intercept at Modulus (E-modulus) (J)	X – Intercept at Modulus (E-modulus) (mm/mm)	Y-Intercept at Modulus (E-modulus) (MPa)	Final area (cm^2)
1	0.09429	0.02132	-147.39958	0.03142
	Final diameter (mm)	Final Length (mm)	Diameter (mm)	Final linear density (tex)
1	2.00000	100.0000	5.10000	
	Extension at Break (standard)(mm)			
1	23.91672			

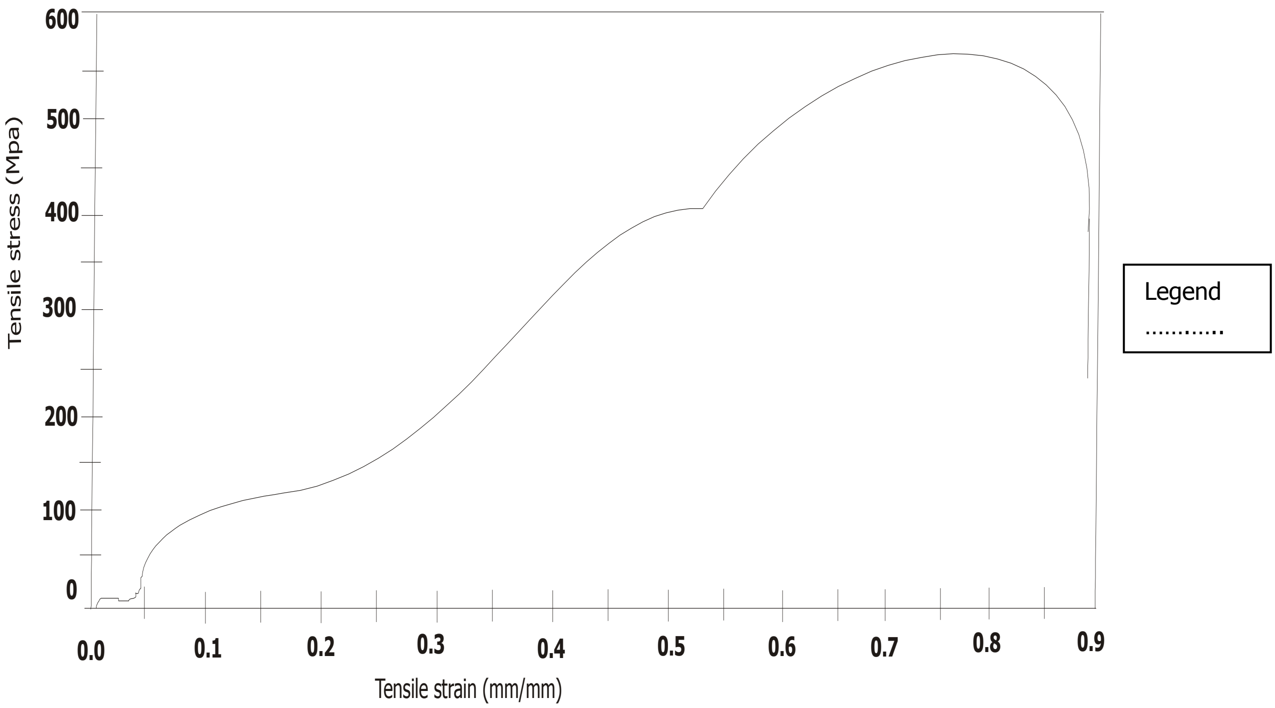

Fig 9: STRESS-STRAIN CURVE FOR PHSM 2 16MM

Table 10: The Resulting Tension, Load, Stress and Strain Result, PSM 1 12MM

	Length (mm)	Maximum load (N)	Tensile strain at maximum load (mm/mm)	Tensile stress of maximum Load (MPa)
1	36.71000	6496.87797	0.77932	318.03467
	Tensile strain at Yield (Zero Slope) (mm/mm)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile Stress at Break (Standard) (MPa)
1	0.66286	0.77636	655.93384	550.70337
	True stress at Break (Standard) (MPa)	Tensile extension at Yield (Zero slope) (mm)	Tensile extension at Break (Standard) (mm)	Energy at Yield (Zero Slope) (J)
1	978.24936	24.33344	28.50031	155.07971
	Energy at Break (Standard) (J)	Load at Yield (Zero Slope) (N)	Load at Break (Standard) (N0	Extension at Maximum Load (mm)
1	208.27452	13399.55181	11249.88124	28.60890
	Extension at Yield (Zero Slope) (mm)	Tensile extension at Maximum Load (mm)	True strain at Break (Standard) (mm/mm)	True strain at Maximum Load (mm/mm)
1	27.41656	32.93062	0.63891	0.64030
	True stress at Maximum Load (MPa)	True strain at Yield (Zero Slope) (mm/mm)	True stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)
1	488.97932	0.55781	983.1245	1838.62057
	Energy to X-Intercept at Modulus (E-modulus) (J)	X – Intercept at Modulus (E-modulus) (mm/mm)	Y-Intercept at Modulus (E-modulus) (MPa)	Final area (cm^2)
1	0.10867	0.02494	-45.84925	0.03142
	Final diameter (mm)	Final Length (mm)	Diameter (mm)	Final linear density (tex)
1	2.00000	100.0000	5.10000	
	Extension at Break (standard)(mm)			
1	32.83374			

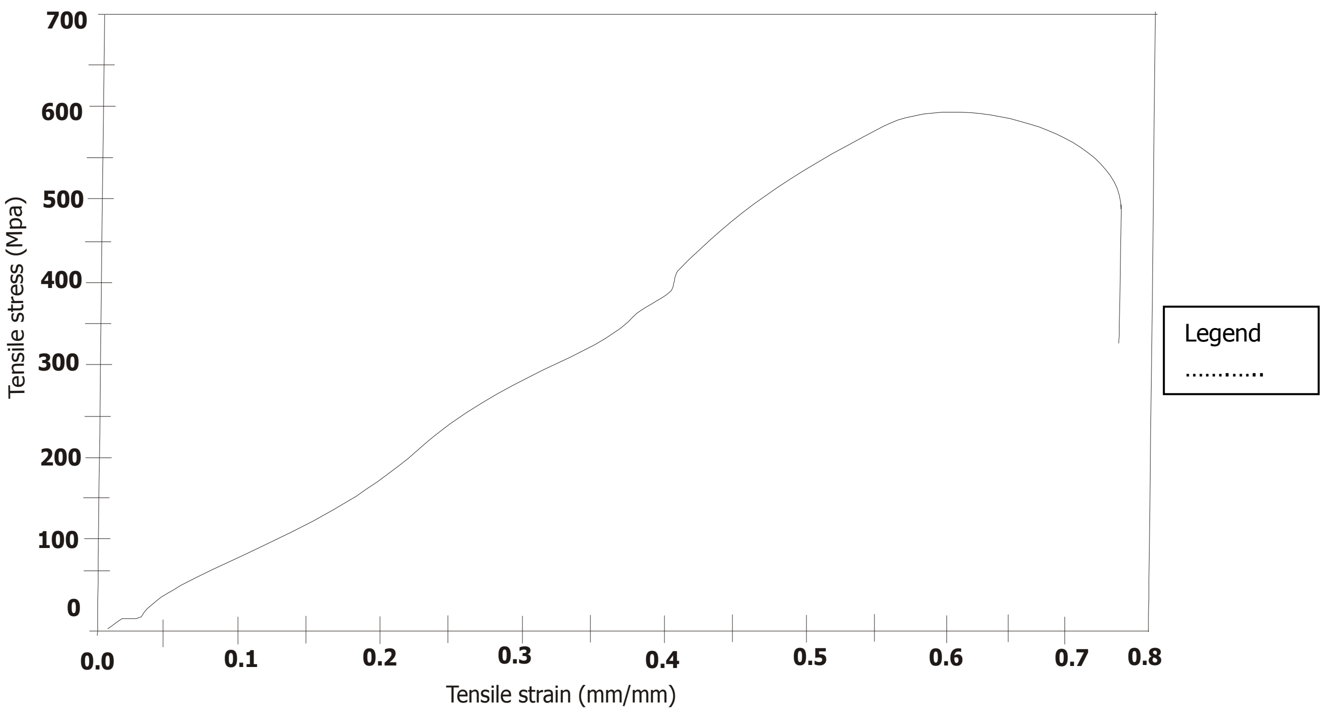

Fig 10: STRESS-STRAIN CURVE FOR PSM 1 12MM

Table 11: The Resulting Tension, Load, Stress and Strain Result, PSM 1 16MM

	Length (mm)	Maximum load (N)	Tensile strain at maximum load (mm/mm)	Tensile stress of maximum Load (MPa)
1	36.95000	4349.16727	0.99775	212.90012
	Tensile strain at Yield (Zero Slope) (mm/mm)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile Stress at Break (Standard) (MPa)
1	0.84575	0.99459	487.12085	360.00668
	True stress at Break (Standard) (MPa)	Tensile extension at Yield (Zero slope) (mm)	Tensile extension at Break (Standard) (mm)	Energy at Yield (Zero Slope) (J)
1	718.06622	31.25031	36.75015	191.02350
	Energy at Break (Standard) (J)	Load at Yield (Zero Slope) (N)	Load at Break (Standard) (N0	Extension at Maximum Load (mm)
1	241.91676	9951.00513	7354.29078	36.86703
	Extension at Yield (Zero Slope) (mm)	Tensile extension at Maximum Load (mm)	True strain at Break (Standard) (mm/mm)	True strain at Maximum Load (mm/mm)
1	24.33343	28.60890	0.57457	0.57623
	True stress at Maximum Load (MPa)	True strain at Yield (Zero Slope) (mm/mm)	True stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)
1	565.88604	0.50854	1090.72337	812.40540
	Energy to X-Intercept at Modulus (E-modulus) (J)	X – Intercept at Modulus (E-modulus) (mm/mm)	Y-Intercept at Modulus (E-modulus) (MPa)	Final area (cm^2)
1	0.11613	0.02500	-20.30759	0.03142
	Final diameter (mm)	Final Length (mm)	Diameter (mm)	Final linear density (tex)
1	2.00000	100.0000	5.10000	
	Extension at Break (standard)(mm)			
1	28.50031			

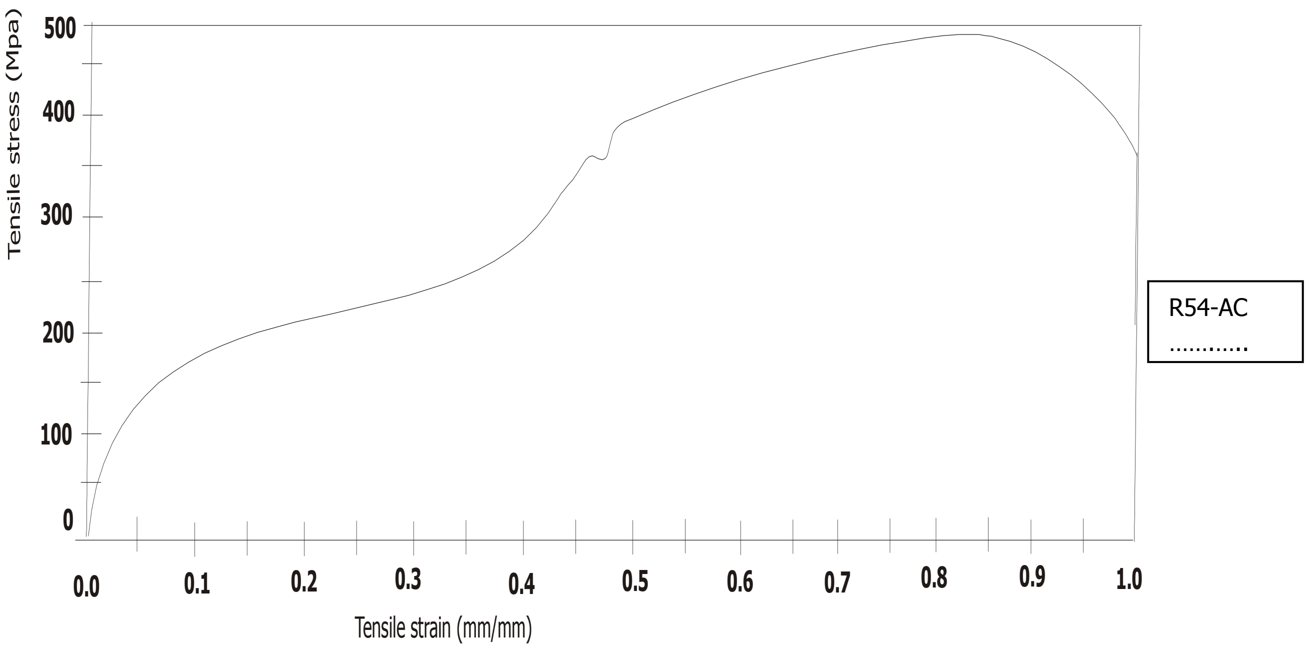

Fig 11: STRESS-STRAIN CURVE FOR PSM 1 16MM

Table 12: The Resulting Tension, Load, Stress and Strain Result, PSM 2 12MM

	Length (mm)	Maximum load (N)	Tensile strain at maximum load (mm/mm)	Tensile stress of maximum Load (MPa)
1	36.71000	6385.35023	0.88675	312.57520
	Tensile strain at Yield (Zero Slope) (mm/mm)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile Stress at Break (Standard) (MPa)
1	0.30405	0.88306	33.74331	560.82007
	True stress at Break (Standard) (MPa)	Tensile extension at Yield (Zero slope) (mm)	Tensile extension at Break (Standard) (mm)	Energy at Yield (Zero Slope) (J)
1	1056.05626	1.24984	32.41703	0.15048
	Energy at Break (Standard) (J)	Load at Yield (Zero Slope) (N)	Load at Break (Standard) (N0	Extension at Maximum Load (mm)
1	201.61466	689.31528	11456.54842	32.55249
	Extension at Yield (Zero Slope) (mm)	Tensile extension at Maximum Load (mm)	True strain at Break (Standard) (mm/mm)	True strain at Maximum Load (mm/mm)
1	31.25031	36.86703	0.69044	0.69202
	True stress at Maximum Load (MPa)	True strain at Yield (Zero Slope) (mm/mm)	True stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)
1	425.32214	0.61288	899.10125	2999.98245
	Energy to X-Intercept at Modulus (E-modulus) (J)	X – Intercept at Modulus (E-modulus) (mm/mm)	Y-Intercept at Modulus (E-modulus) (MPa)	Final area (cm^2)
1	-------	-0.00119	3.57849	0.03142
	Final diameter (mm)	Final Length (mm)	Diameter (mm)	Final linear density (tex)
1	2.00000	100.0000	5.10000	
	Extension at Break (standard)(mm)			
1	36.75015			

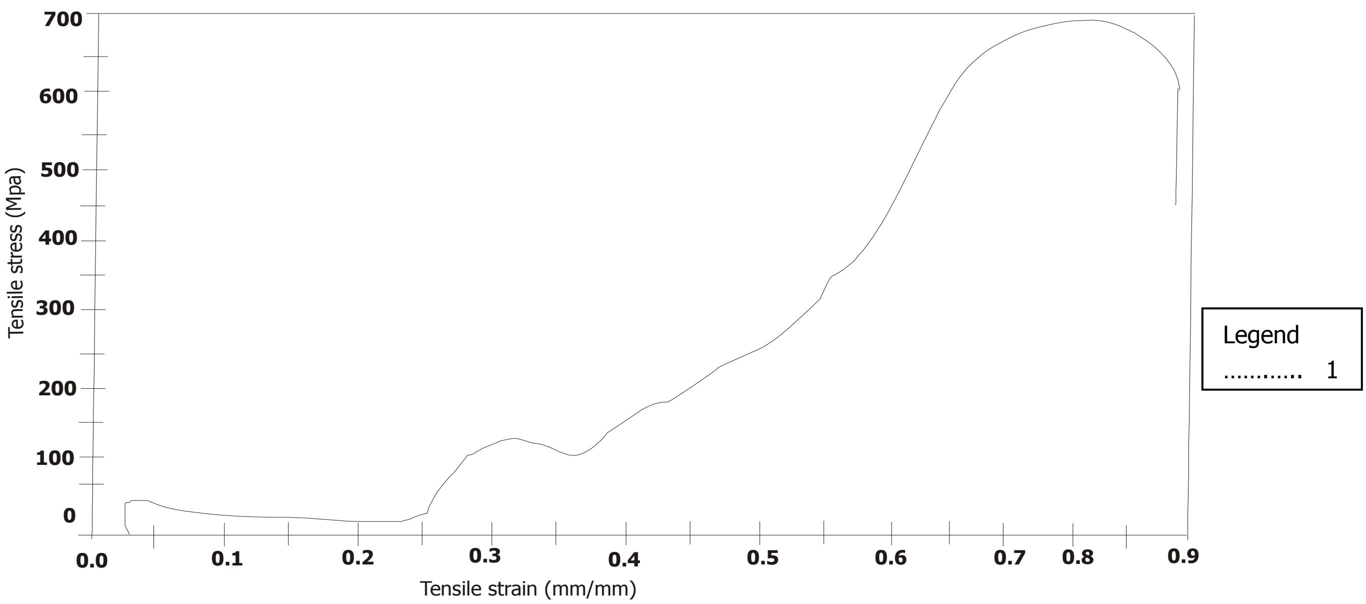

Fig 12: STRESS-STRAIN CURVE FOR PSM 2 12MM

Table 13: The Resulting Tension, Load, Stress and Strain Result, PSM 2 16MM

	Length (mm)	Maximum load (N)	Tensile strain at maximum load (mm/mm)	Tensile stress of maximum Load (MPa)
1	36.71000	4371.61140	0.81007	213.99879
	Tensile strain at Yield (Zero Slope) (mm/mm)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile Stress at Break (Standard) (MPa)
1	0.67421	0.80588	476.21097	381.59143
	True stress at Break (Standard) (MPa)	Tensile extension at Yield (Zero slope) (mm)	Tensile extension at Break (Standard) (mm)	Energy at Yield (Zero Slope) (J)
1	689.10719	24.75031	29.58375	139.97517
	Energy at Break (Standard) (J)	Load at Yield (Zero Slope) (N)	Load at Break (Standard) (N0	Extension at Maximum Load (mm)
1	184.46139	9728.13591	7795.22806	29.73750
	Extension at Yield (Zero Slope) (mm)	Tensile extension at Maximum Load (mm)	True strain at Break (Standard) (mm/mm)	True strain at Maximum Load (mm/mm)
1	1.24984	32.55249	0.63290	0.63485
	True stress at Maximum Load (MPa)	True strain at Yield (Zero Slope) (mm/mm)	True stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)
1	589.75037	0.03348	34.89215	1840.77702
	Energy to X-Intercept at Modulus (E-modulus) (J)	X – Intercept at Modulus (E-modulus) (mm/mm)	Y-Intercept at Modulus (E-modulus) (MPa)	Final area (cm^2)
1	6.33387	0.30754	-566.11841	0.03142
	Final diameter (mm)	Final Length (mm)	Diameter (mm)	Final linear density (tex)
1	2.00000	100.0000	5.10000	
	Extension at Break (standard)(mm)			
1	32.41703			

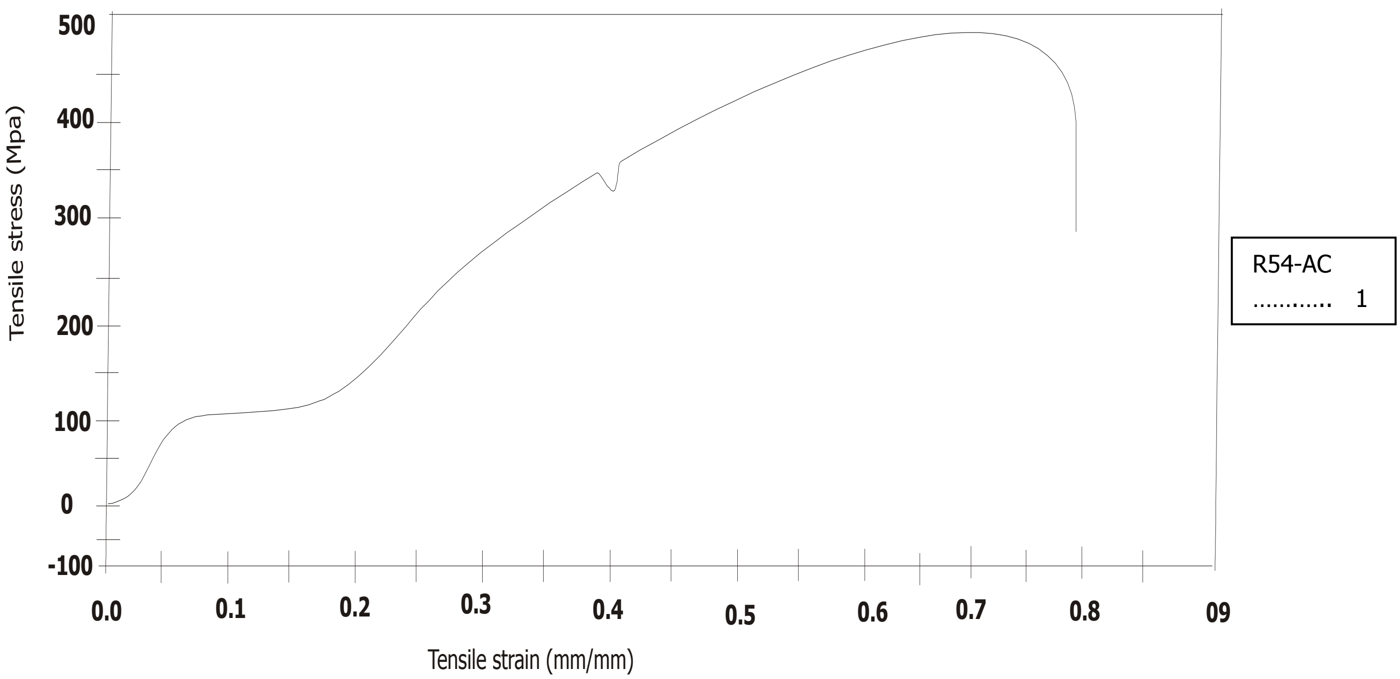

Fig 13: STRESS-STRAIN CURVE FOR PSM 2 16MM

Table 14: The Resulting Tension, Load, Stress and Strain Result, IM 1 12MM

	Length (mm)	Maximum load (N)	Tensile strain at maximum load (mm/mm)	Tensile stress of maximum Load (MPa)
1	36.71000	6183.83996	0.65400	302.71088
	Tensile strain at Yield (Zero Slope) (mm/mm)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile Stress at Break (Standard) (MPa)
1	0.16798	0.65152	51.83211	503.21042
	True stress at Break (Standard) (MPa)	Tensile extension at Yield (Zero slope) (mm)	Tensile extension at Break (Standard) (mm)	Energy at Yield (Zero Slope) (J)
1	831.06262	6.16656	23.91734	3.18832
	Energy at Break (Standard) (J)	Load at Yield (Zero Slope) (N)	Load at Break (Standard) (N0	Extension at Maximum Load (mm)
1	154.04035	1058.83703	10279.68600	24.00828
	Extension at Yield (Zero Slope) (mm)	Tensile extension at Maximum Load (mm)	True strain at Break (Standard) (mm/mm)	True strain at Maximum Load (mm/mm)
1	24.75031	29.73750	0.59105	0.59336
	True stress at Maximum Load (MPa)	True strain at Yield (Zero Slope) (mm/mm)	True stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)
1	387.35179	0.51534	797.2776	3158.15983
	Energy to X-Intercept at Modulus (E-modulus) (J)	X – Intercept at Modulus (E-modulus) (mm/mm)	Y-Intercept at Modulus (E-modulus) (MPa)	Final area (cm^2)
1	0.13559	0.03620	-144.32005	0.03142
	Final diameter (mm)	Final Length (mm)	Diameter (mm)	Final linear density (tex)
1	2.00000	100.0000	5.10000	
	Extension at Break (standard)(mm)			
1	29.58375			

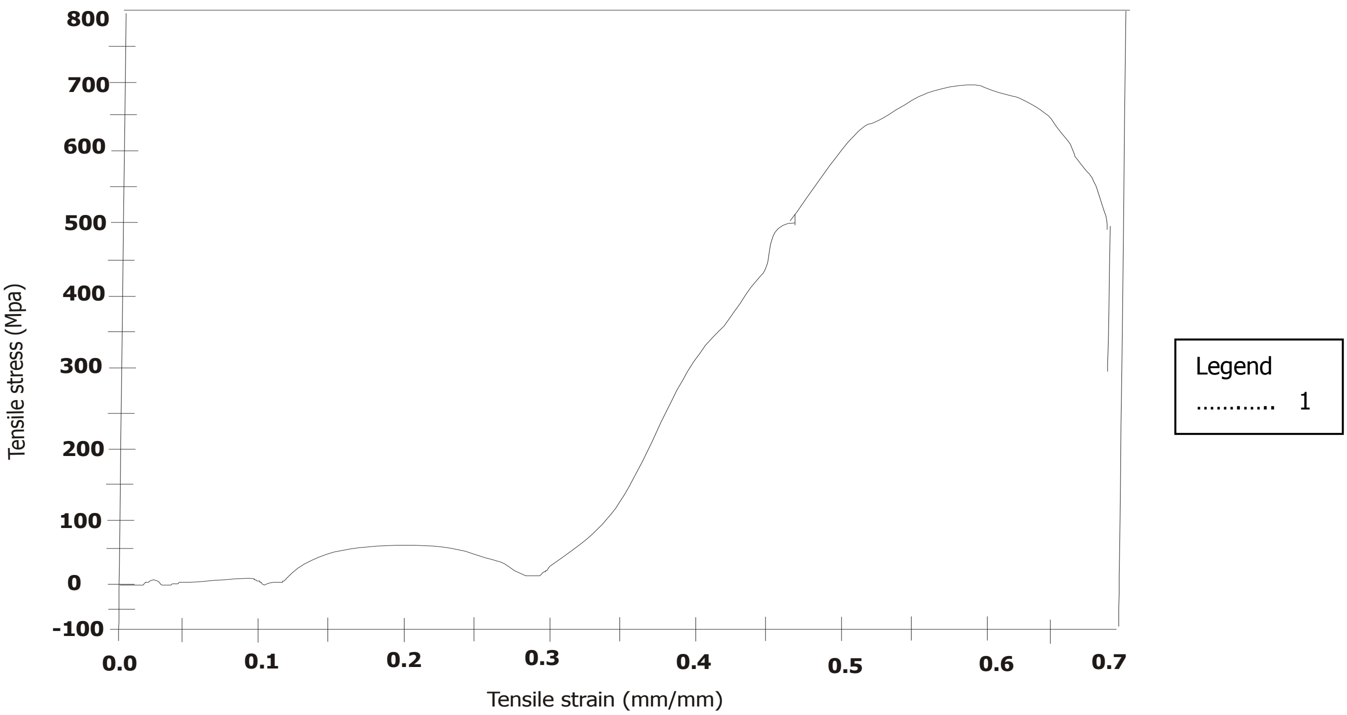

Fig 14: STRESS-STRAIN CURVE FOR IM 1 12MM

Table 15: The Resulting Tension, Load, Stress and Strain Result, IM 1 16MM

	Length (mm)	Maximum load (N)	Tensile strain at maximum load (mm/mm)	Tensile stress of maximum Load (MPa)
1	36.71000	5235.08303	0.45160	256.26740
	Tensile strain at Yield (Zero Slope) (mm/mm)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile Stress at Break (Standard) (MPa)
1	0.30873	0.44721	654.46106	463.92947
	True stress at Break (Standard) (MPa)	Tensile extension at Yield (Zero slope) (mm)	Tensile extension at Break (Standard) (mm)	Energy at Yield (Zero Slope) (J)
1	671.40469	11.33344	16.41718	73.31585
	Energy at Break (Standard) (J)	Load at Yield (Zero Slope) (N)	Load at Break (Standard) (N0	Extension at Maximum Load (mm)
1	134.55216	13369.46487	9477.24655	16.57828
	Extension at Yield (Zero Slope) (mm)	Tensile extension at Maximum Load (mm)	True strain at Break (Standard) (mm/mm)	True strain at Maximum Load (mm/mm)
1	6.16656	24.00828	0.50170	0.50320
	True stress at Maximum Load (MPa)	True strain at Yield (Zero Slope) (mm/mm)	True stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)
1	500.68327	0.15528	60.53889	817.75169
	Energy to X-Intercept at Modulus (E-modulus) (J)	X – Intercept at Modulus (E-modulus) (mm/mm)	Y-Intercept at Modulus (E-modulus) (MPa)	Final area (cm^2)
1	0.00056	0.00885	-7.23596	0.03142
	Final diameter (mm)	Final Length (mm)	Diameter (mm)	Final linear density (tex)
1	2.00000	100.0000	5.10000	
	Extension at Break (standard)(mm)			
1	23.91734			

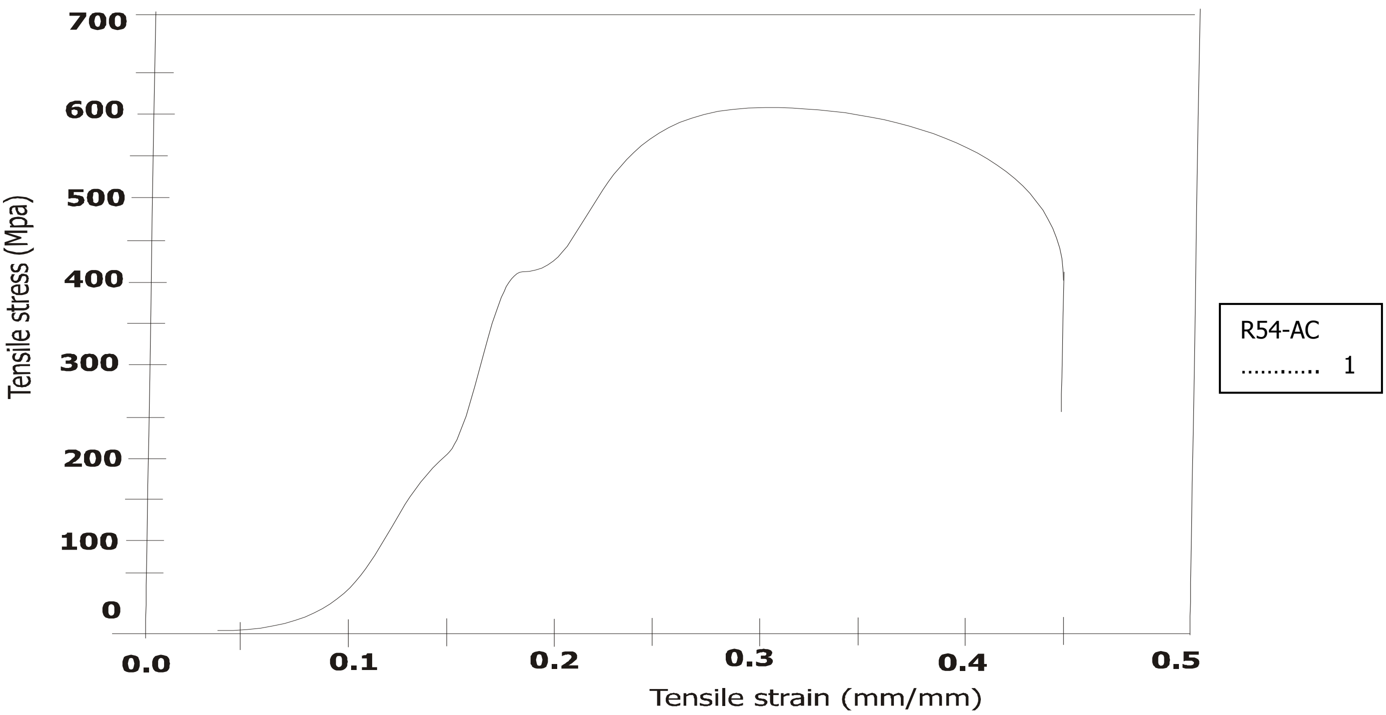

Fig 15: STRESS-STRAIN CURVE FOR IM 1 16MM

Table 16: The Resulting Tension, Load, Stress and Strain Result, IM 2 12MM

	Length (mm)	Maximum load (N)	Tensile strain at maximum load (mm/mm)	Tensile stress of maximum Load (MPa)
1	36.71000	5700.51596	0.48029	279.05124
	Tensile strain at Yield (Zero Slope) (mm/mm)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile Stress at Break (Standard) (MPa)
1	0.33822	0.47672	682.21759	480.04425
	True stress at Break (Standard) (MPa)	Tensile extension at Yield (Zero slope) (mm)	Tensile extension at Break (Standard) (mm)	Energy at Yield (Zero Slope) (J)
1	708.88989	12.41609	17.50031	95.72039
	Energy at Break (Standard) (J)	Load at Yield (Zero Slope) (N)	Load at Break (Standard) (N0	Extension at Maximum Load (mm)
1	159.92241	13936.48088	9806.44301	17.63156
	Extension at Yield (Zero Slope) (mm)	Tensile extension at Maximum Load (mm)	True strain at Break (Standard) (mm/mm)	True strain at Maximum Load (mm/mm)
1	11.33344	16.57828	0.36964	0.37267
	True stress at Maximum Load (MPa)	True strain at Yield (Zero Slope) (mm/mm)	True stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)
1	371.99804	0.26906	856.51204	6996.20514
	Energy to X-Intercept at Modulus (E-modulus) (J)	X – Intercept at Modulus (E-modulus) (mm/mm)	Y-Intercept at Modulus (E-modulus) (MPa)	Final area (cm^2)
1	0.52616	0.10427	-729.50134	0.03142
	Final diameter (mm)	Final Length (mm)	Diameter (mm)	Final linear density (tex)
1	2.00000	100.0000	5.10000	
	Extension at Break (standard)(mm)			
1	16.41718			

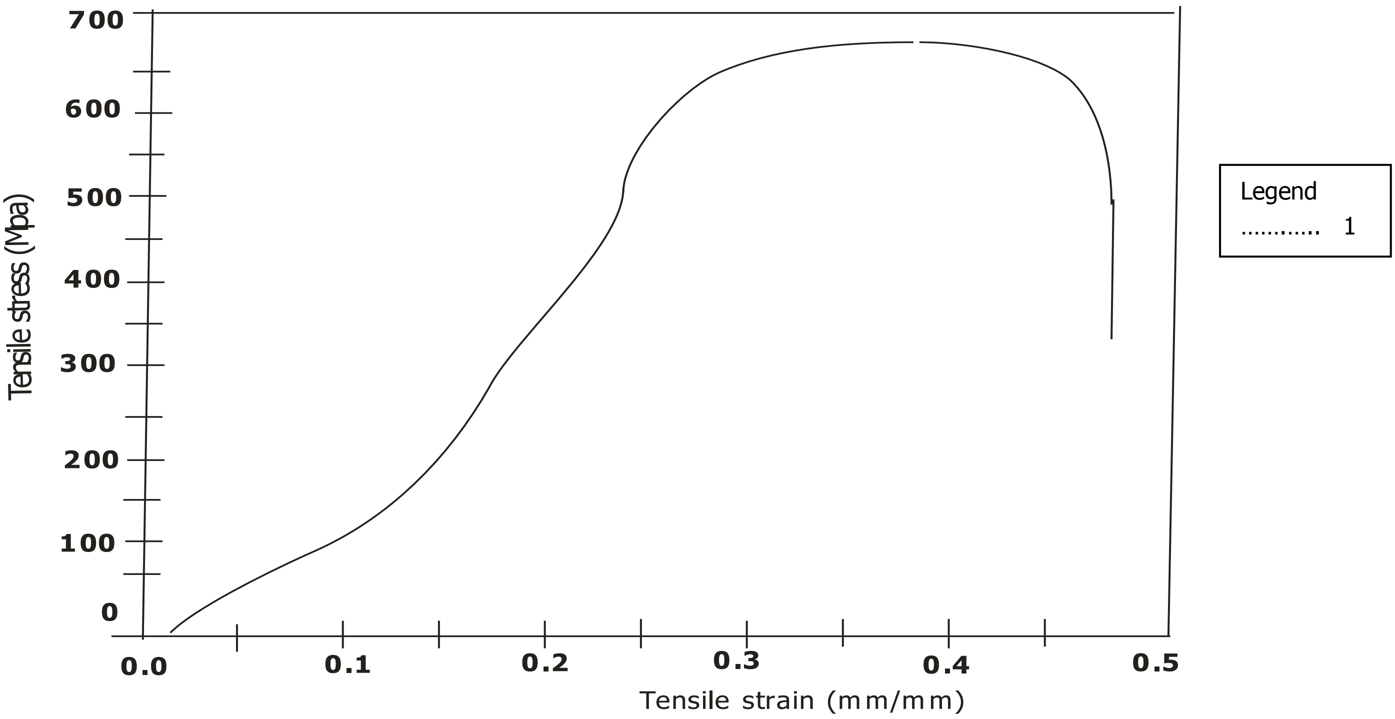

Fig 16: STRESS-STRAIN CURVE FOR IM 2 12MM

Table 17: The Resulting Tension, Load, Stress and Strain Result, IM 2 16MM

	Length (mm)	Maximum load (N)	Tensile strain at maximum load (mm/mm)	Tensile stress of maximum Load (MPa)
1	36.71000	5660.25563	0.78556	277.08041
	Tensile strain at Yield (Zero Slope) (mm/mm)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile Stress at Break (Standard) (MPa)
1	0.24516	0.78317	319.05264	469.86893
	True stress at Break (Standard) (MPa)	Tensile extension at Yield (Zero slope) (mm)	Tensile extension at Break (Standard) (mm)	Energy at Yield (Zero Slope) (J)
1	837.85795	8.99984	28.75031	28.70213
	Energy at Break (Standard) (J)	Load at Yield (Zero Slope) (N)	Load at Break (Standard) (N0	Extension at Maximum Load (mm)
1	236.99644	6517.67328	9598.57926	28.27453
	Extension at Yield (Zero Slope) (mm)	Tensile extension at Maximum Load (mm)	True strain at Break (Standard) (mm/mm)	True strain at Maximum Load (mm/mm)
1	12.41609	17.63156	0.38982	0.39224
	True stress at Maximum Load (MPa)	True strain at Yield (Zero Slope) (mm/mm)	True stress at Yield (Zero Slope) (MPa)	Modulus (E-modulus) (MPa)
1	413.07760	0.29134	912.95783	3580.72205
	Energy to X-Intercept at Modulus (E-modulus) (J)	X – Intercept at Modulus (E-modulus) (mm/mm)	Y-Intercept at Modulus (E-modulus) (MPa)	Final area (cm^2)
1	0.82165	0.05474	-196.02203	0.03142
	Final diameter (mm)	Final Length (mm)	Diameter (mm)	Final linear density (tex)
1	2.00000	100.0000	5.10000	
	Extension at Break (standard)(mm)			
1	17.50031			

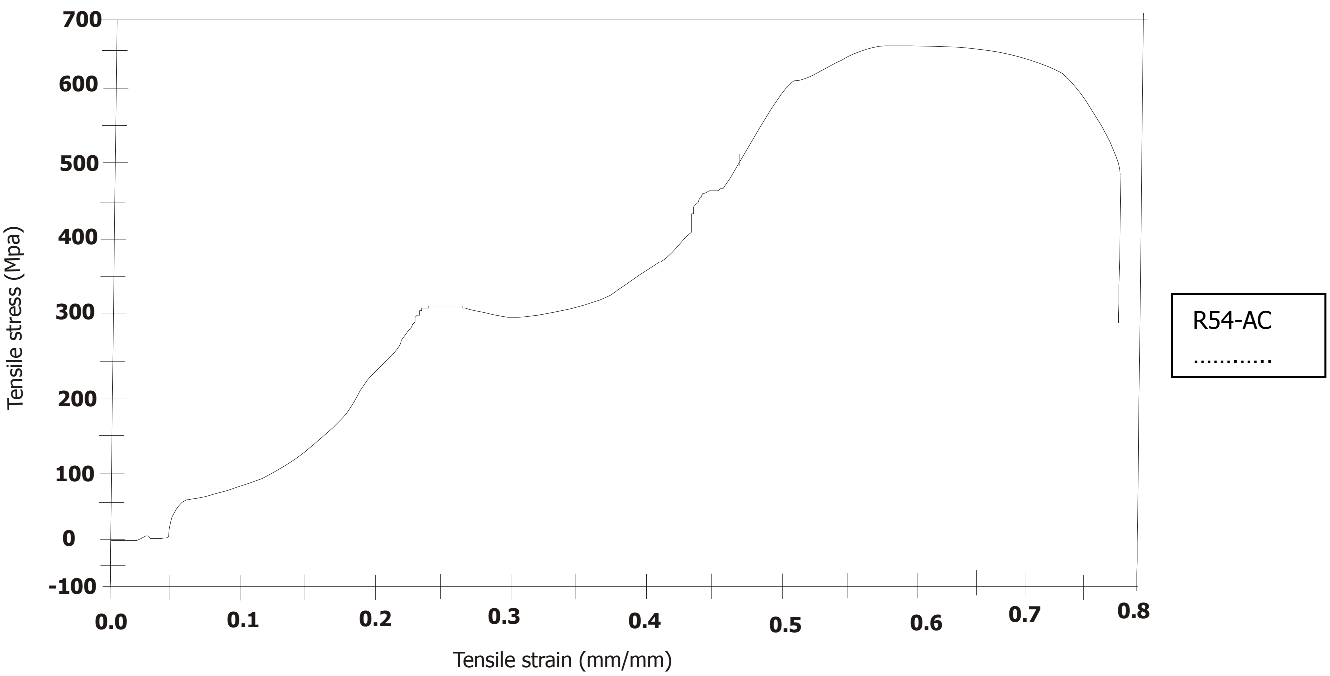

Fig 17: STRESS-STRAIN CURVE FOR IM 2 16MM

Summary of test results are presented below;

Table 18: Summary of Test Result for UTS, YS and BS

	12mm/1st Reading (N/cm^2)	2nd Reading (N/cm^2)	16mm/1st Reading (N/cm^2)	2nd Reading (N/cm^2)
IFSM	UTS = 19224 Yield = 39743 Break/s = 34381	18617 39591 31952	17536 38653 31952	19124 39514 32477
PHSM	UTS = 18043 Yield = 38542 Break/s = 30622	16072 39244 28036	18408 34733 30618	16759 36591 27711
PSM	UTS = 20678 Yield = 42647 Break/s = 35805	20328 21939 36463	13842 31671 23406	13913 30962 24809
IM	UTS = 19681 Yield = 33699 Break/s = 32717	18143 44355 31211	16662 42551 30163	18015 20744 30549
STANDARD	UTS = 34000 Yield = 22500 Elongation= 20%	34000 22500 20%	42000 28000 20%	42000 28000 20%

Table 19: HARDNESS RESULTS

Sample	1st Reading (HRC)	2nd Reading (HRC)	3rd Reading (HRC)	Average (HRC)
IFMS 16mm	242.8	247.6	240.6	243.6
IFMS 12mm	284.7	289.7	288.6	287.6
IM 16mm	301.7	300.9	294.5	299.0
IM 16mm	295.5	300.5	298.0	298.0
PHSM 16mm	269.7	267.4	272.1	269.7
PHSM 12mm	256.3	258.6	260.0	258.3
PSM 16mm	229.5	234.6	232.5	232.2
PSM 12mm	290.5	288.7	290.8	290.0

IV. CONCLUSIONS

Based on the mechanical properties experimental data obtained for the locally made steel and the imported steel rods. The following conclusions can be drawn:

[1] The Nigerian locally made steel rods from recycled scraps showed the same mechanical properties as those of the imported steel rods.

[2] The locally made steel and the imported steel rods showed stress values and hardness which are in conformity with the international standards; however their ultimate tensile stress steel is below the international standards.

[3] The variation in the hardness of the steel rods can be rationalized based on the non-uniformity in the microstructure of the steel rods

[4] Generally, there is need for proper time to time assessment of manufactured steel rod mechanical properties before any product is used for construction purposes to avoid the problem that may arise due to inconsistency.

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