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Full Length Research Paper

Effect of immersion speed on the mechanical properties and micro-structure of oil quenched AISI 1020 steel

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Steel is one of the most important commodities in the engineering world due to its usefulness and availability. Its application is wider than any other metal, ranging from domestic use in the forms of utensils and many more to its use in construction and manufacturing industries. The wide range of application of steel in engineering practices has prompted the desire to increase certain mechanical properties to meet engineering requirements through heat treatment. In this work, samples of the specimen were purchased at a local market and the spectrometry analysis was carried out. The steel samples were machined into required shape, heat-treated and cooled under different immersion speeds. The effects of immersion speeds on the mechanical properties (hardness, % elongation, tensile strength, modulus of elasticity and yield strength) and microstructure of the quenched AISI 1020 were investigated. The result obtained revealed an improvement in the mechanical properties of the materials at different immersion speed.

Key words: Heat treatment, mechanical properties, microstructure, AISI 1020.

INTRODUCTION

Carbon steel is a type of steel where the main interstitial alloying constituent is Carbon in the range of 0.12 to 2.0% (Çalik, 2009; Sharma et al., 2012; Fadare, 2011). The American Iron and Steel Institute (AISI) defines Carbon steel as a steel in which no minimum content is specified or required for Chromium, Cobalt, Molybdenum, Nickel, Niobium, Titanium, Tungsten, Vanadium, Zirconium, or any other element added to obtain a desired alloying effect. According to Odusote et al. (2012), steels with Carbon content varying from 0.25 to 0.65% are classified as medium Carbon, while those with Carbon content less than 0.25% are termed low Carbon. The Carbon content of high Carbon steels usually ranges within 0.65 to 1.5%.

Generally, the mechanical properties of plain Carbon

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Table 1. Composition of the low-Carbon steel.

C (%)	Si (%)	Mn (%)	S (%)	P (%)	Cr (%)	Ni (%)	Cu (%)
0.189	0.207	0.497	0.021	0.022	0.101	0.073	0.174

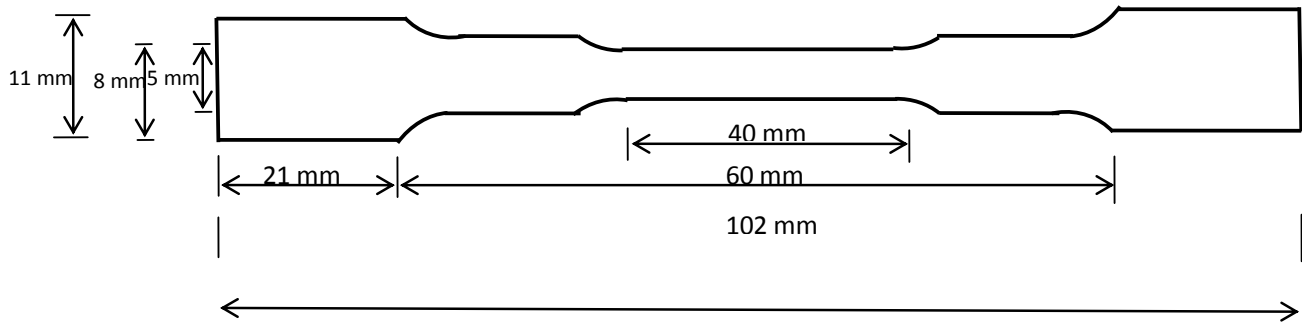

Figure 1. Machined specimen for tensile test.

steels increases with the increased Carbon concentration dissolved in austenite prior to quenching during hardening heat treatment, which may be due to transformation of austenite into martensite (Odusote et al., 2012). Therefore, the mechanical strength of medium Carbon steels can be improved by quenching in appropriate medium. The major influencing factors in the choice of the quenching medium are the kind of heat treatment to be employed, composition of the steel, the sizes and shapes of the parts (Odusote et al., 2012).

Quenching is a common manufacturing process aiming to produce components with desirable properties such as low residual stresses and distortions, avoidance of cracks, specific hardness, and achievement of improved properties (Mackerle, 2003). Low Carbon steel which was employed in the course of this study has high malleability and ductility, good machinability, good surface finish, good formability and general availability.

MATERIALS AND METHODS

Samples of steel bar purchased from a local market in Oyo State, South-Western Nigeria, were cut into 25 mm diameter and 100 mm long. Also, the determination of the chemical composition of the specimen was carried out using Minipal 4 Spectrometer (Table 1).

Specimen preparation

Each specimen was prepared for hardness and tensile tests. The samples were machined into standard specifications for tensile testing using Monsanto Tensiometer, following standard test procedures in accordance with the ASTM E8M-91 standards (1992) (Figure 1). An optical metallurgical microscope XJL-17 model with magnification 10×10 was used for taken the micrograph of the samples.

Heating and quenching process

Heating of the specimen was carried out at the metrology laboratory of the Mechanical Engineering Department, Ladoke Akintola University of Technology, Nigeria. This process involved heating the tensile specimen to an austenising temperature of 850°C. The material was maintained at this temperature for 1 h and then quenched at various immersion speeds of 0.3102, 0.3241, 0.3384, and 0.4167 m/s respectively, using oil as the quenchant.

Mechanical tests

After quenching operation, the materials were returned to the Engineering Materials Development Institute (EMDI) Akure, where the effects of the quenching at different immersion speeds on the physical and microstructural properties of the steel samples were determined.

Microstructure analysis

The microstructural analysis was obtained using an optical metallurgical microscope. 20 mm cylindrical rods were cut from each sample, grounded, polished and etched in Nital prior to microstructural analysis. The microstructure was taken with magnification of 500.

Hardness test

Prior to testing, specimens were mounted using phenolic powder, grinded and polished to obtain a smooth surface. A direct load of

Table 2. Mechanical properties of quenched low Carbon steel at different immersion speeds.

Immersion speed (m/s)	Tensile strength (N/mm^2)	% elongation	Modulus of elasticity	Yield strength (N/mm^2)	Hardness (Case)	Hardness (Core)
0.3102	82.18	55.8	5674.3	312.1	166.25	162.55
0.3241	71.05	53.1	8836.9	298.7	158.35	132
0.3384	81.68	46.5	4642.9	215.4	136.3	110.95
0.4167	70.39	42.6	10576.8	241.2	157.85	115.3

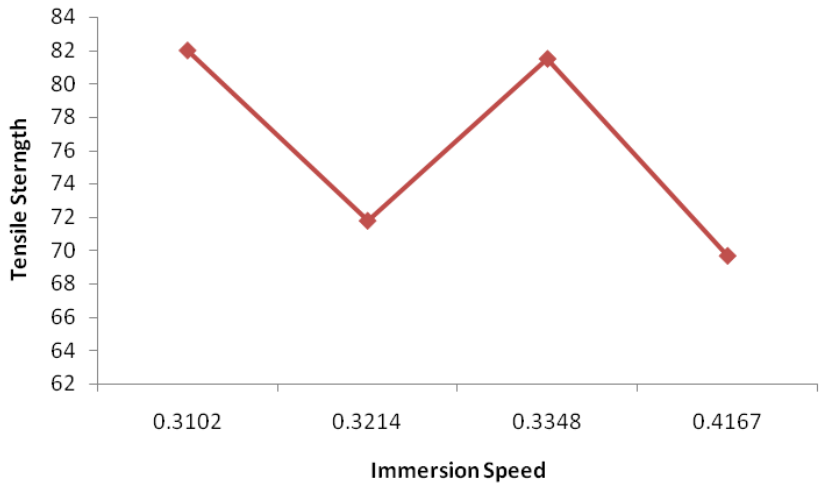

Figure 2. Tensile strength (N/mm^2) against Immersion speed (m/s).

490 N was applied for a dwell time of 10 s and hardness readings were evaluated using Leitz 8299 micro-hardness tester. The indentation was square shaped. Diagonal length of square was measured by scale attached on the microscope. Hardness was obtained directly from the chart given in the manual for corresponding load and diagonal length. Multiple hardness tests were performed on each sample and the average of the values was taken as a measure of the hardness value for each specimen.

Tensile test

P2000 electronic tensiometer was used to conduct the test following standard test procedures in accordance with the ASTM E8M-91 standards (1992). The samples were tested at a nominal strain rate of 10^{-3}/s until fracture. The tensile properties evaluated from the engineering stress-strain curves developed from the tension test are – the ultimate tensile strength (σ_u), the yield strength (σ_y), and the strain to fracture (ε_f).

RESULTS AND DISCUSSION

Effect of heat treatment on mechanical properties

The effect of immersion speed on the mechanical properties (ultimate tensile strength, hardness, toughness, percentage elongation, and percentage reduction) of the quenched steel is shown in the Table 2.

Effect on tensile strength

As the immersion speed of the quenched steel increases, the tensile strength of the samples fluctuates, resulting in variation between the tensile strength and speed of immersion. In Figure 2, it was observed that at low immersion speed of 0.3102 m/s, maximum tensile strength of 82.18 N/mm^2 was obtained. At the highest immersion speed of 0.4167 m/s, the tensile strength reduces to 70.39 N/mm^2 which shows no stable relationship between the immersion speed and the tensile strength.

Effect on percentage elongation

Figure 3 shows the relationship between the percentage elongation and immersion speed. As immersion speed

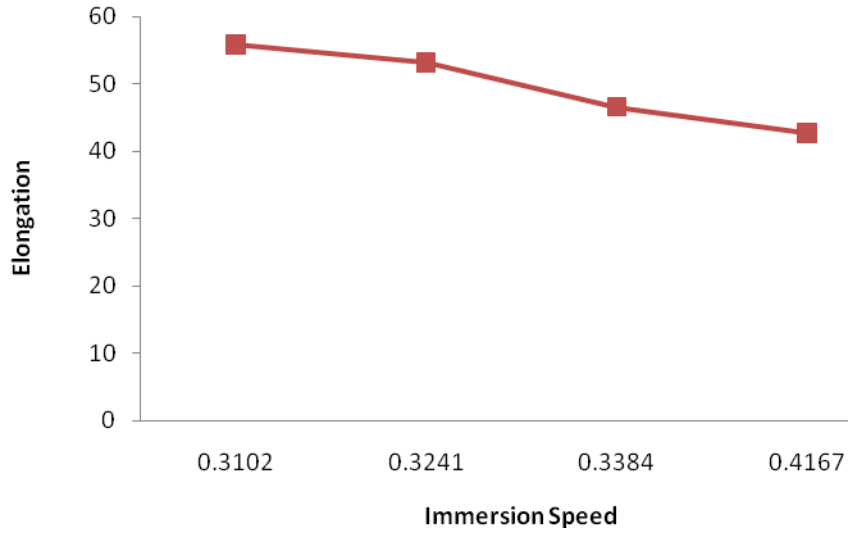

Figure 3. Percentage elongation against immersion speed (m/s).

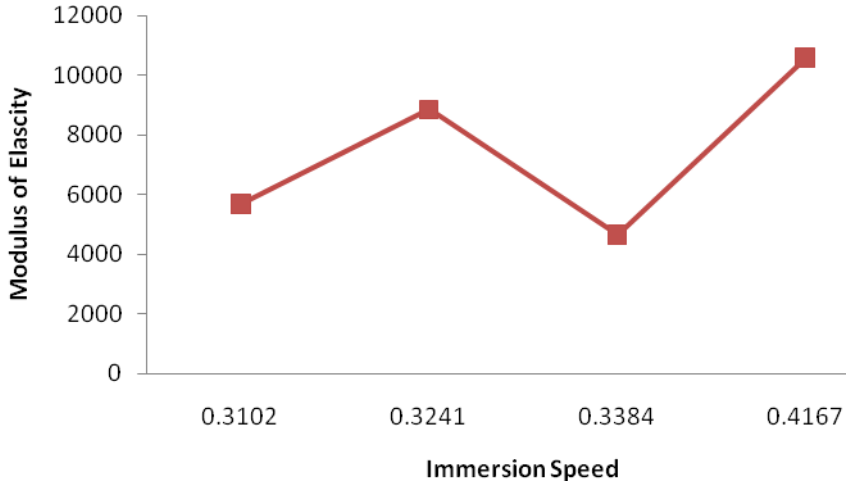

Figure 4. Modulus of elasticity (N/mm^2) against Immersion speed (m/s).

increases, the percentage elongation of the specimens decreases. This shows an inverse relationship between the percentage elongation and immersion speed. At a low immersion speed of 0.3102 m/s, high percentage elongation of 55.15% was obtained above which the percentage elongation of the samples decreases.

Effect on elasticity

The modulus elasticity of the quenched mild steel samples also fluctuates in relation with increased immersion speed. From Figure 4, the modulus of elasticity increases from 5674.3 to 8836.9 as the immersion speed increases from 0.3102 to 0.3214 m/s. For the next immersion speed of 0.3384 m/s, the modulus of elasticity drops drastically to 4642.9 and increases to 10576.8 for the increased immersion speed of 0.4167 m/s.

Effect on yield strength

Figure 5 shows the relationship between the yield

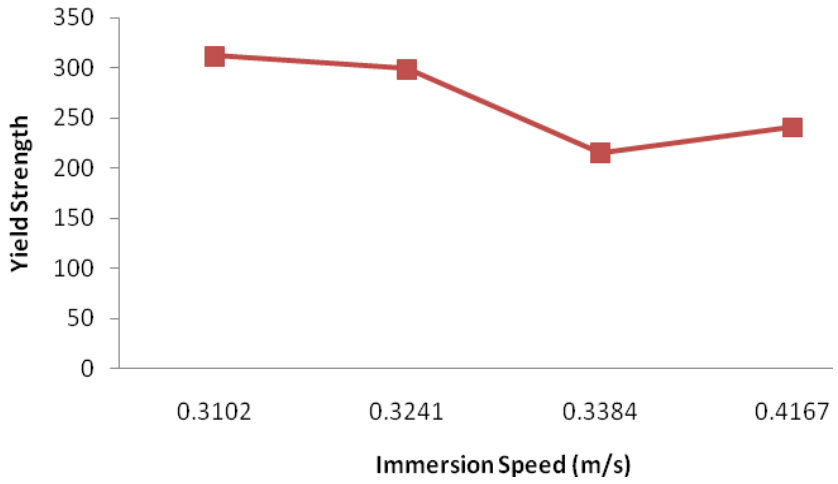

Figure 5. Yield Strength (N/mm^2) against Immersion speed (m/s).

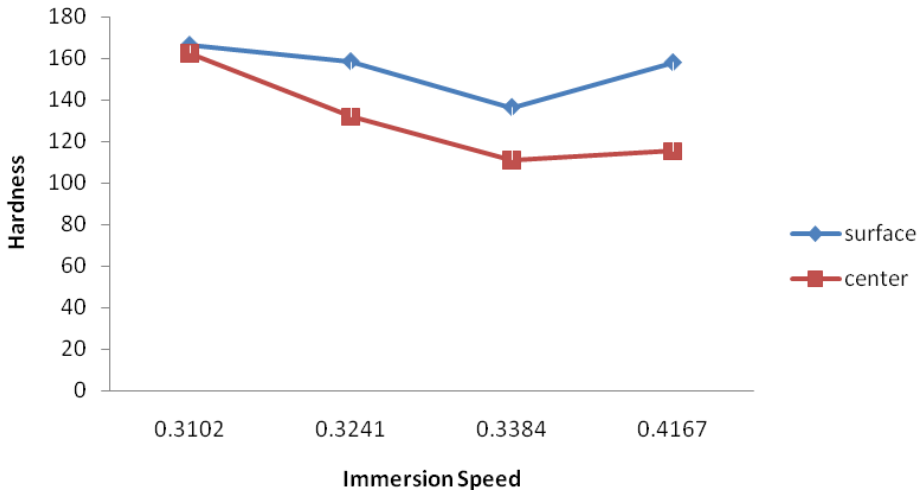

Figure 6. Hardness value (BHN) against immersion speed (m/s) (surface and center).

strength and immersion speed. The yield strength of the steel samples reduces with increase in immersion rate from 0.3102 to 0.3384 m/s. Optimum yield strength of 310 was obtained at low immersion speed of 0.3102 m/s.

Effect on hardness

There is a notable difference between the hardness of the steel samples at the surface and at the center (Figure 6). Although, the hardness of the specimens had an inverse relation with the immersion speed, i.e. the higher the speed of immersion, the lower the hardness value at both the surface and the center. It was evidence that the hardness values at the surface of the samples are higher than that at the center. This can be attributed to the fact that quenching occurs faster and more rapidly at the surface than at the center.

Effect of immersion speed on the microstructure of the steel

The micrographs of the steel samples quenched at different immersion speed were shown in Figures 7 to 10. The massive martensite structure of hardened sample,

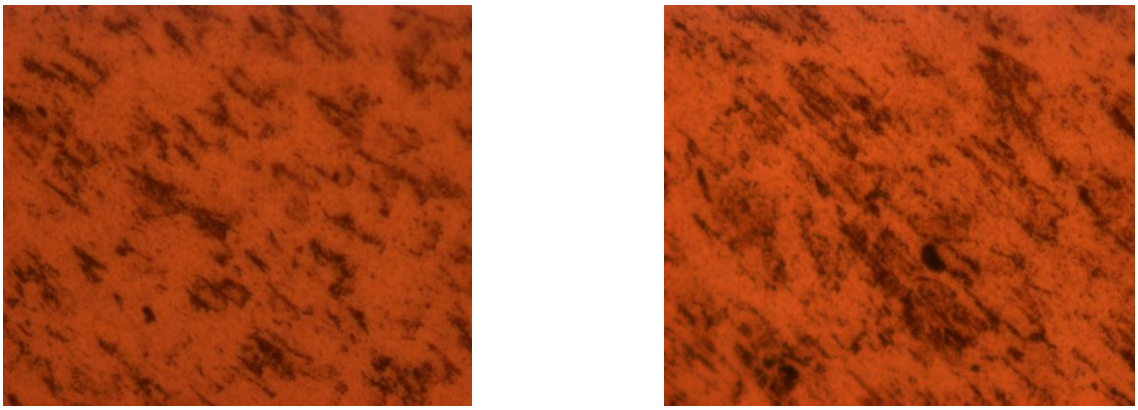

Figure 7. Microstructure of oil quenched steel at immersion rate of 0.3102 m/s.

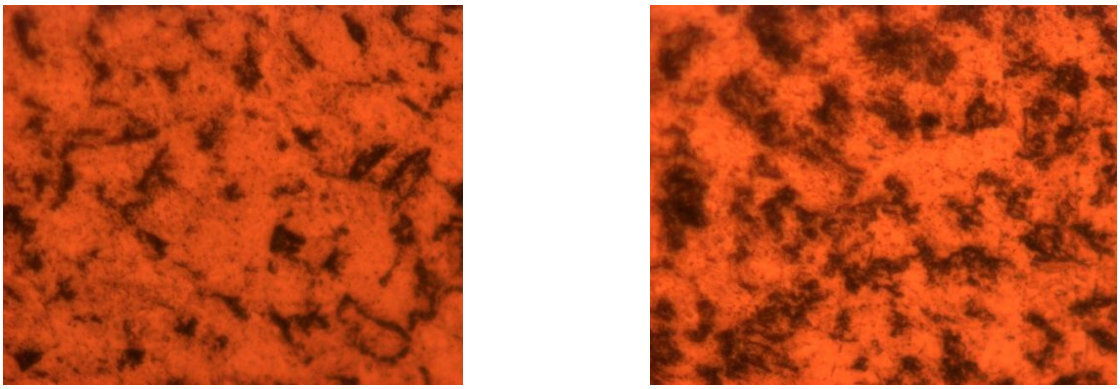

Figure 8. Microstructure of oil quenched steel at immersion rate of 0.3241 m/s.

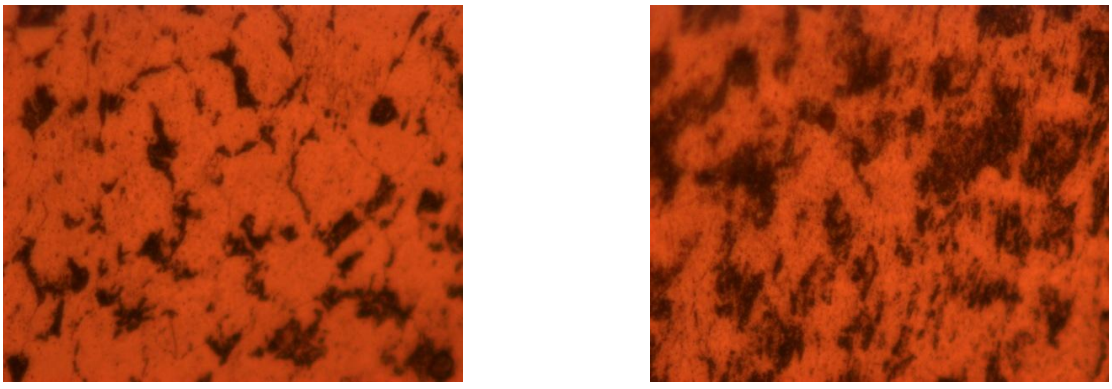

Figure 9. Microstructure of oil quenched steel at immersion rate of 0.3384 m/s.

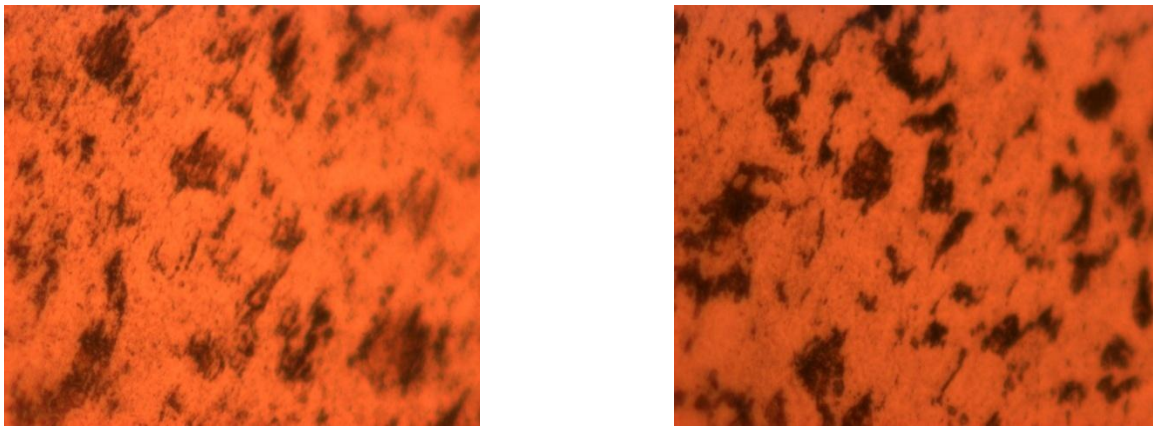

Figure 10. Microstructure of oil quenched steel at immersion rate of 0.4167 m/s.

when low Carbon steels are rapidly quenched from its austenite temperature to room temperature, the austenite will decompose into a mixture of some medium Carbon martensite and fewer pearlite as a result increases the tensile strength, hardness and little reduction in ductility of the material. In this study, it was observed that the surface (outer layer) of the steel samples cooled more rapidly resulting in large martensitic formation. Little pearlite were noticed at the surface compared to the center (inner layer). This varied effect may be due to the fact that the surface has contact with the oil quenchant; hence, cools faster than the center. The high martensitic composition may make the material very hard and brittle. As the speed of immersion decreases, the martensitic formation also decreases, giving room for more pearlite formation, hence decrease in the hardness as the speed of immersion increases. Obviously, the rates of immersion bring about a variation in the hardness of the material.

Conclusions

The speeds of immersion have varying effects on individual mechanical properties of AISI 1020. Mechanical properties such as yield strength and percentage elongation decreases while young modulus increases as the material is quenched. The tensile strength of the mild steel samples varied as the immersion speeds. The effect of immersion speeds on the hardness of the steel differs at the center and at the core. As the immersion speed increases, the hardness at the surface increases as compared to the hardness value at the center of the mild steel samples.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Effect of battery effluent on plasticity and swelling characteristics of expansive soil

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Ground pollution is perpetuated by humans due to many reasons. Industrial activity is necessary for the socio-economic progress of a country, but at the same time, it generates large amount of solid and liquid wastes. Among various means available, disposal through land is simple and widely used. All types of pollution have either direct or indirect effect on soil properties. Behaviour of any contaminant in soil depends upon the physical and chemical properties of the contaminant as well as its interactivity with that of soil. The effect of battery effluent on plasticity, swelling characteristics of black cotton soil has been presented in this paper. The soil used in this investigation falls under "SC" group as per I.S. classification and its differential free swell index is 254.54% indicating very high degree of expansiveness. The battery effluent used in this investigation is a colourless liquid and soluble in water.

Key words: Plasticity, expansive soil, battery effluent.

INTRODUCTION

The index and engineering properties of the ground gets modified in the vicinity of the industrial plants mainly as a result of contamination by the industrial wastes disposed. The major sources of surface and subsurface contamination are the disposal of industrial wastes and accidental spillage of chemicals during the course of industrial operations. The leakages of industrial effluent into subsoil directly affect the use and stability of the supported structure.

Extensive damage to the floors, pavements and foundations of a light industrial building in Kerala State was reported by Sridharan et al. (1981; 2002). Joshi et al. (1994) reported that severe damage occurred to the interconnecting pipe of a phosphoric acid storage tank in particular and also to the adjacent buildings due to differential movements between pump and acid tank foundations of fertilizer plant in Calgary, Canada. A similar case of accidental spillage of highly concentrated caustic soda solution as a result of spillage from cracked drains in an industrial establishment in Tema, Ghana caused considerable structural damage to a light industrial building in the factory, in addition to localized

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Table 1. Properties of soil.

S/No	Property		Value
		Atterberg limits	
1	(a)	Liquid Limits	77%
	(b)	Plastic limit	30%
	(c)	Plasticity index	47%
	(d)		
		Compaction characteristics	
2	(a)	Maximum dry Unit Weight	18.48 kN/m^3
	(b)	Optimum Moisture Content	12.8%
3	Specific Gravity		2.76

Table 2. Chemical composition of battery effluent.

S/No.	Parameter	Value
1.	Color	White
2.	pH	8.45
3.	Sulphates	250 mg/L
4.	Chlorides	30 mg/L
5.	Lead monoxide	27.77%
6.	Lead sulfate	63.08%
7.	Free lead	7.44%
8.	Total lead	75.42%
9.	BOD	110 mg/L
10.	COD	320 mg/L

subsidence of the affected area (Kumaplay and Ishola, 1985). Therefore, it is better to start ground monitoring from the beginning of a project instead of waiting for complete failure of the ground to support human activities and then start the remedial actions.

Expansive soils have high shrinkage and swelling characteristics. In general, these soils are very much sensitive to changes in environment. The environment includes the stress system, the chemistry of pore water in the system, the seasonal variations in ground water table and temperature variations. Hence, an attempt is made in this investigation to study the effect of battery effluent on the plasticity and swelling characteristics of an expansive soil.

MATERIALS AND METHODS

The soil used for this investigation is obtained from Tirupati (India). The soil is classified as 'SC' as per I.S. Classification indicating that it is clayey sand. It is highly expansive as the free swell index is 254.5%. The properties of the soil are given in Table 1. Battery effluent is a colorless liquid and soluble in water in proportions. The chemical properties of the effluent are shown in Table 2.

Procedure for contamination

The soil from the site is dried and the pebbles and vegetative matter present, if any, are removed by hand. It is further dried and pulverized and sieved through a sieve of 4.75 mm to eliminate gravel fraction, if any. The soil mixed with different percentages of battery effluent, from 0 to 100%, in increments of 20%. The contaminated soil prepared thus is stored for a day in air tight containers for uniform distribution of battery effluent. The soil effluent mixtures are mixed thoroughly before testing.

Tests conducted

The following tests are conducted in the presented investigation:

Liquid limit tests

Liquid limit tests are conducted at various percentages of battery effluent. About 120 g of an air-dried sample passing through 425 µ I.S. sieve is taken in a dish and mixed with certain amount of water to form a uniform paste. A portion of this paste is placed in the cup of the liquid limit device and surface is smoothened and leveled with a spatula to a maximum depth of 10 mm. A groove is cut through the sample along the symmetrical axis of the cup, preferably in one stoke, using a standard grooving tool. After the soil pat has been cut by a proper grooving tool, the handle is turned

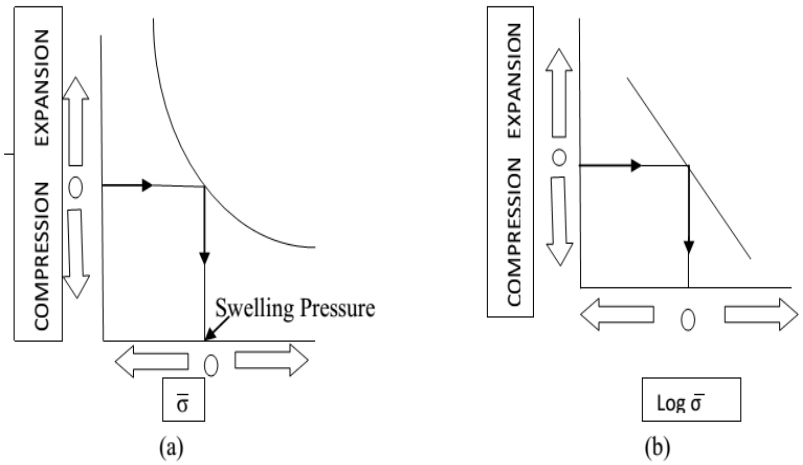

Figure 1. Pressure-volume change plots.

at a rate of 2 revolutions per second until the two parts of the soil sample come into contact at the bottom of the groove along a distance of 12 mm. About 15 g of soil near the closed groove is taken for water content determination. The liquid limit is the water content at which the soil is sufficient fluid to flow when the device is given 25 blows. As it is difficult to get exactly 25 blows for the sample to flow, the test is conducted at different water contents so as to get blows in the range of 10 to 40. The soil in the cup is transferred to the dish containing the soil paste and mixed thoroughly after adding more water. The soil sample is again taken in the cup of the liquid limit device and the test is repeated.

Plastic limit tests

About 30 g of soil, passing through 425 µ I.S. Sieve, is taken in evaporating dish. It is mixed thoroughly with water till it becomes plastic, and can be easily moulded with fingers. About 10 g of the plastic soil mass is taken in one hand and a ball is formed. The ball is rolled with fingers on a glass plate to form a soil thread of uniform diameter. The rate of rolling is kept about 80 to 90 strokes per minute. If the diameter of the thread becomes approximately 3 mm and if it starts just crumbling that water content is known as the plastic limit.

SWELLING CHARACTERISTICS

Differential free swell index

This test is conducted on the local soil contaminated with battery effluent in varying percentages from 0 to 100% in increments of 20%. Two samples of the dried soil weighing 10 g each passing through 425 µ I.S. sieve are taken. One sample is put slowly in a 100 ml graduated glass cylinder having kerosene (a non-polar liquid). The other sample is similarly put in another 100 ml glass cylinder having distilled water. Both the samples are left for 24 h and then their volumes are noted. Differential free swell index is calculated by the formula given below:

$$DFSI = \frac{(V_1 - V_2)}{V_2} \times 100$$

V_1 = Soil volume in distilled water, V_2 =Soil volume in kerosene.

Swelling pressure

This test is conducted on the local soil contaminated with battery effluent in varying percentages from 0 to 100% in increment of 20%, such as 0, 20, 40, 60, 80 and 100%. Two methods are in common use for measuring the swelling pressure of soils in the laboratory. In the first method, the swelling pressure of an undisturbed or a remolded soil is measured for 'no volume change' condition. The method requires continuous adjustment of pressure on the soil specimen taken in a consolidation cell, so that the soil volume at any time is equal to its initial volume. Details of the test procedure are given in IS: 2720 (Pert XLI)- 1977. Remolded specimens are taken at the density and moisture content of the field soil, as for example, in an earth embankment where the moisture content of compaction and the required compacted density are known. Undisturbed specimens, taken carefully from the field soil, are tested for estimating the swelling behavior of an existing deposit.

The second method consists of taking a few (more than three) initially identical soil specimens in consolidation cells of fixed ring type, subjecting them to different magnitudes of pressures and then allowing the soil to saturate. Under the different load intensities, some of the soil specimens would compress after saturation while some others would swell. In fact, the load intensities ought to be properly selected to produce this kind of differential behavior. After the volume change (compression or swelling) is complete and has been recorded, load intensity versus volume change plot is obtained (Figure 1a). From this plot, the pressure corresponding to zero volume change is read and is denoted as the swelling pressure for the soil. It is much more convenient to a plot the load intensity to a logarithmic scale, as this would produce a straight line (Figure 1b).

RESULTS AND DISCUSSION ON PLASTICITY CHARACTERISTICS

Consistency represents the relative ease with which the soil can be deformed. This term is mostly used for

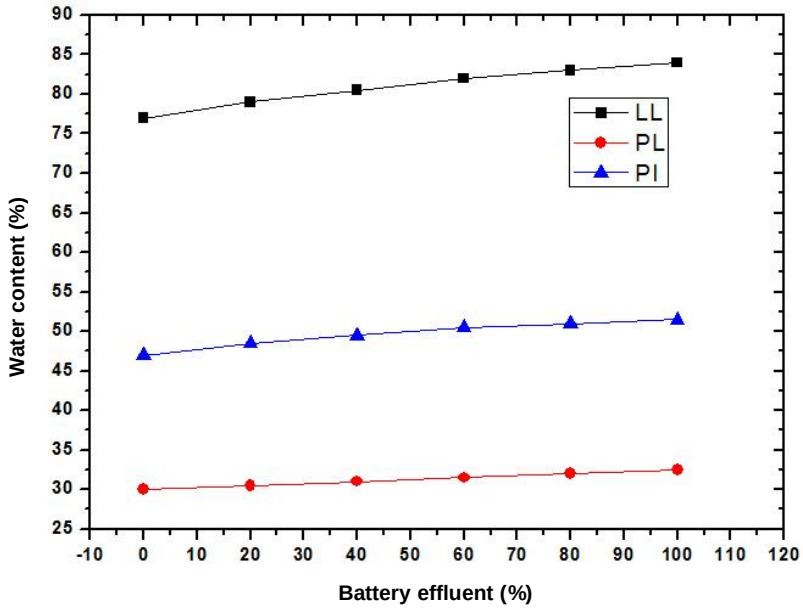

Figure 2. Variation of LL, PL and PI with battery effluent.

fine-grained soils for which the consistency is related to a large extent to water content. Atterberg (1911) formally distinguished the following states of consistency – liquid, plastic, semi-solid and solid. The water contents at which the soil passes from one of these states to the next have been arbitrarily designated as consistency limits-liquid limit, plastic limit, and shrinkage limit, in that order. Liquid limit is the water content corresponding to the arbitrary limit between liquid and plastic states of consistency of a soil. The minimum water content at which the soil made a standard grove by a Casagrande tool will flow together for a distance of 12.5 mm under the impact of 25 numbers of blows in a carasgrande apparatus. It is also defined as the maximum water content at which the soil is still in the liquid state, but has a small shearing strength against flowing, which can be measured by standard available means. Plastic limit is the water content at which a soil will just begin to crumble when rolled into a thread of approximately 3 mm in diameter. Plasticity index is defined as the numerical difference between the liquid limit and plastic limit of a soil. When soil is contaminated with battery effluent at various percentages such as 0, 20, 40, 60, 80 and 100%, the liquid limit, plastic limit and plastic index may vary.

The results of liquid limit and plastic limit tests conducted at different percentage of battery effluent are presented in Figure 2. From this figure, it is found that the liquid limit value of the contaminated soil increases slightly with the increase in percentage of battery effluent. The plastic limit value of the uncontaminated soil is 30%. From this figure, it is found that plastic limit value of contaminated soil increases with increase in percentage of battery effluent. The plasticity index of uncontaminated soil is 47%. The plasticity index values of the contaminated soil increase with percentage increase in battery effluent. Consistency limits (liquid limit, plastic limit, and plastic index) and swelling pressures increases due to absorption of sulphates that is known to be present in battery effluent on to the clay surface. Absorption of sulphates causes expansion of double layer leading to increase in consistency limits and swelling pressure.

Swelling characteristics

Expansive soils or swelling soils are those soils, which have the tendency to increase in volume when water is available and to decrease in volume if water is removed. These volume changes in swelling soils are the cause of many problems in structures that come into their contact or constructed out of them. From the engineering point of view, it will be sufficient to get an indication of the possible swelling behavior by performing simple tests. Almost all over the world, the surface/surficial deposits consist of expansive (block cotton) soils, which are found to be problematic for engineering construction. These expansive (black cotton) soils on coming into contact with water heave considerably and lose strength. If swelling is not allowed, swelling pressure of varying order occurs. Swelling pressure of the order of 150 to 300 kPa is commonly encountered. Though problematic for engineering construction, nevertheless, a large number of major and minor irrigation projects must necessarily be

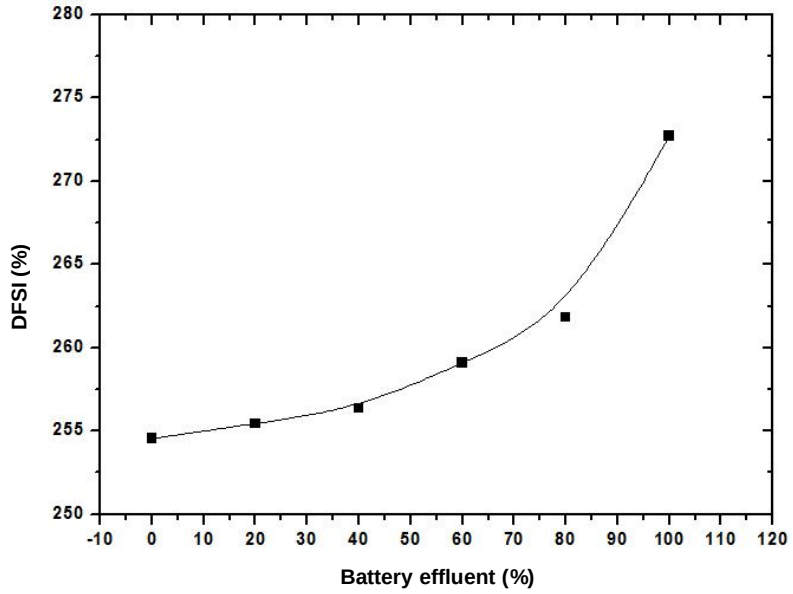

Figure 3. Variation of DFSI with battery effluent.

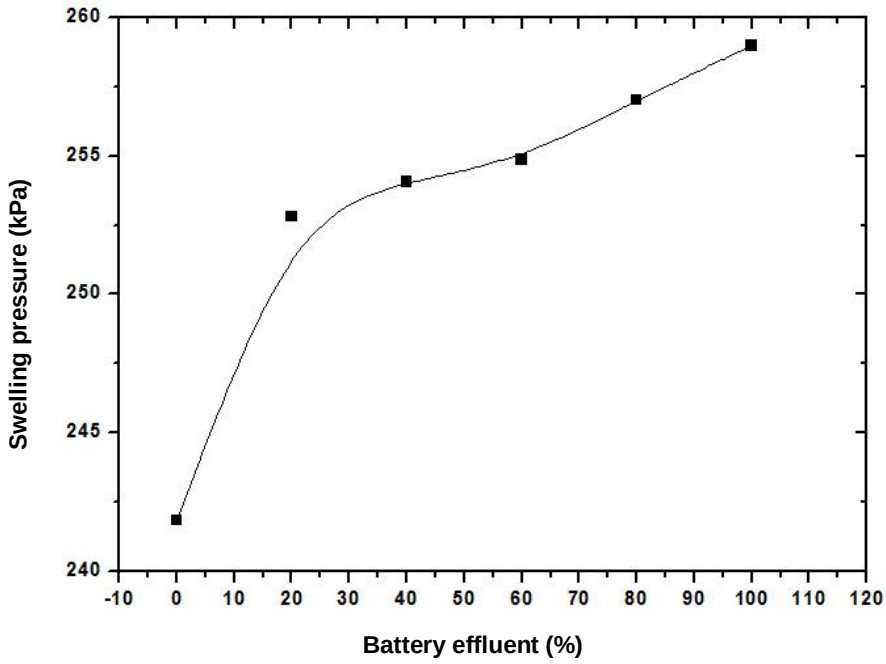

Figure 4. Variation of swell pressure with battery effluent.

executed in such soils. They are almost mainly encountered in all the regions of the world. The variation of differential free swell index with percent battery effluent is shown in Figure 3. From the figure, it is observed that the differential free swell index increases slightly with percent increase in battery effluent. The percent increase in the differential free swell index is about 7 at 100% of battery effluent.

Swelling pressure of the soil admixed with the various percentages of battery effluent are determined and presented in Figure 4. The value of swelling pressure of natural soil is 246 kPa. From the figure, it is observed that

there is slightly increasing trend from 0 to 100% battery effluent.

Conclusions

Based on experimental results, the following conclusions are drawn. If increasing battery effluent, liquid limit and plastic limits are increased. Swelling characteristic like differential free swell index and swelling pressure are also increased with increasing battery effluent. Further more study is required in micro level to under stand the behaviour of soil when mixing with battery effluent.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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