Engineering and Economical Analysis for Using Iron Swarf in Concrete Pavement

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DEDICATION

TO

My Late Father

My Mother, My Wife
My Brother and Sisters.

ACKNOWLEDGEMENT

All thanks for **My God** for the help and strength that he gave me to complete this thesis.

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ABSTRACT

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There is a critical need to improve the engineering properties of the concrete pavements in general by a minimum cost. This study focused on improving the engineering properties of the concrete pavement by using the steel swarf in its mix.

Experimental tests and statistical analysis were used in order to investigate the goodness of the previous assumption and the swarf content effect on the properties of the fresh and hardened concrete and the concrete durability. A steel swarf contents of (0.0, 0.85, 1.7, 2.55 and 3.4)% of the total weight were used to prepare the concrete specimens.

In order to achieve the previous steps, the work was started by specifying the properties of the used material (water, cement, aggregate and steel swarf), then a mix design was prepared to provide the required strength, workability and durability.

Results indicate that workability can be increased to its maximum value using a 1.4-percent swarf concrete. It is also possible to increase the flexural strength and the splitting tensile strength of the hardened concrete by (15 &25)% respectively, using a 0.85-percent swarf concrete.

Results also indicate that the compressive strength, density and the modulus of elasticity still statistically accepted, despite of the simple reduction in its results at some swarf contents.

Concrete durability results, which were obtained by studying the concrete surface resistance against skidding, water and air permeability, show that there was no improvement in its properties due to swarf addition, but concrete durability still statistically accepted.

The improvements that were obtained in concrete workability, flexural and splitting strength using steel swarf content of 0.85%, have several economical benefits that were discussed. Beside the environmental benefits that can be gained because of the steel swarf action in the pollution and other environmental problems.

CHAPTER ONE

INTRODUCTION

CHAPTER ONE

INTRODUCTION

1.1 Preface.

Highway networks are considered a major support for economy elements at any country. Their importance is due to the following reasons:

- It has a major issue in the society development.
- The economy sectors development (industry, tourism, agriculture, security, etc) depends on the highway networks efficiency.
- The yearly accident rate decreases as the highway networks length and its quality increased.
- Highway network construction has a high percentage of the budget at any country.

In Jordan the total length of the highway networks until 1990 is (6000) km, table (1.1) shows the yearly development of the vehicles number, constructed highways length, and the total of the injured and deaths due to accidents.

Table (1.1). Vehicles Number, Constructed Highways length, and Number of (Injured & deaths) During 1983-1996.

(Siyam, 1992 and Jordan Insurance Federation, 1998)

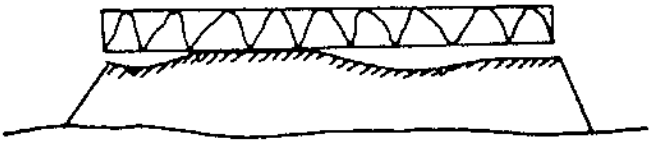
Year	Veh.No	Totally Constructed Highways (km)	Injured and Deaths
1983	197783	5273	8621
1984	211657	5444	9436
1985	220954	5507	9624
1986	232361	Not available	8705
1987	242216	= =	9352
1988	249590	= =	7117
1989	251447	= =	9829
1990	254777	6007	10764
1991	259196	Not available	10505
1992	276301	= =	11064
1993	291347	= =	12194
1994	304893	= =	12959
1995	321373	= =	13653
1996	342337	= =	15927

1.2 General.

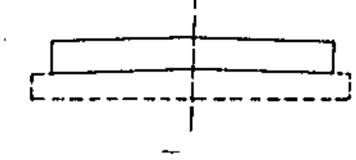
1.2.1 Concrete Pavements.

Pavements have been divided into the following types:

- The flexible pavement, which consists of a relatively thin wearing surface built over a base course and subbase course, and they rest upon the compacted subgrade.
- The rigid pavement, often-called concrete pavement, which consists of a relatively thin Portland cement concrete slab, poured on the subgrade or a base course. The load-carrying capacity of the pavement-base-subgrade structure is brought largely by "beam action" of the pavement, as shown in figure (1.1).



The Beam Action of the Rigid Pavement.

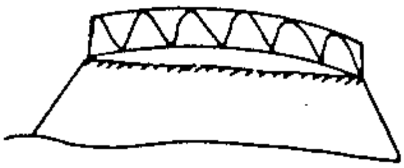


The Rigid Pavement on Base Course.

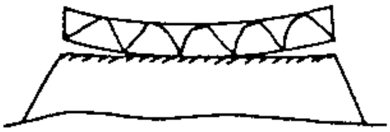
Fig (1.1). The Beam Action of the Rigid Pavement, and the Rigid Pavement on a Base Course. (sharif, 1982).

Base courses could be used under a rigid pavement for a variety of reasons and functions including pumping control, frost action, drainage, control of shrink and swell of the subgrade, expedition of construction and structural improvement.

Since the concrete slab is the major component of the surface, stresses in concrete pavement have been given a detailed consideration by many investigators. Rigid pavement stresses can result from several causes; volumetric changes in the subgrade or/and subbase, restrained temperature movements, changes in moisture content and traffic loads, figure (1.2) shows the thermal stresses action on the pavement form.



The Rigid Pavement at Day.



The Rigid Pavement at Night.

Fig (1.2). Thermal Stresses Action on the Rigid Pavement during Day and Night. (sharif, 1982).

The rigid pavements are generally classified into the following types, (Yoder, 1975):

- Plain concrete pavement.
- Simply reinforced concrete pavement.
- Continuously reinforced concrete pavement.

In many cases concrete pavement is excellent and suitable for the highways paving, depending on the following advantages, (Sharif, 1982):

1) It's a durable pavement, and can be efficiently used at least for (30 year).
2) It provides an enough friction in the dry conditions.
3) It provides an enough sight in the night.
4) It needs a low maintenance.
5) It provides a comfortable surface for the drivers.

6) Its surface provides an excellent base for a new flexible pavement.

7) It's very suitable for the weak subgrades.

On the other hand concrete pavement has the following disadvantages, (Sharif, 1982):

1) It is complex in construction and design.
2) It needs to be closed from (7-15 day) after construction in order to get enough concrete strength.
3) Its initial cost is double the initial cost of the flexible one, besides the joints cost.
4) It must be constructed in one stage, and can't be constructed in multi stages as the flexible one.
5) Pavement materials will be lost if the roadway route has been changed.
6) Joints construction requires a special labor and machines.
7) The pavement color causes a problem in the sight for drivers in the day.

1.2.2 Concrete.

Portland cement concrete is the most widely used structural material in the world for civil engineering projects.

The term concrete is applicable for many products, but it is most generally used with Portland cement. It consists of Portland cement, water and aggregates, which have been mixed together, placed, consolidated and allowed to solidify and harden.

The Portland cement and water form a paste, which acts as a glue or binder. When fine aggregate is added (aggregate with size range lies between No. 200 mesh sieve and No. 4 sieve) the resulting mixture is termed mortar. Then, when course aggregate is included (aggregate sizes larger than No. 4 sieve), concrete is produced.

Normal concrete consists of about three-fourth aggregate and one-fourth paste, by volume. The paste usually consists of water-cement ratios between (0.4 and 0.7) by weight. Admixtures are some times added to concrete for specific purposes; such as entrain air bubbles, impart color, retard the initial set of the concrete, water proof the concrete, etc. (Peurifoy, 1985).

The success of this universal material can be understood quite easily if the following advantages are considered, (McCormac, 1985):

1) It has a considerable compressive strength as compared to other materials.
2) Concrete has great resistance to the actions of fire and water.
3) Concrete structures are very rigid.
4) It is low maintenance material.
5) As compared with other materials, it has a very long service life.
6) It is usually the only economical material for different applications in construction.
7) A special feature of concrete is its ability to be cast into an extra ordinary variety of shapes from simple slabs, beams, columns, and pavement to the great shells.
8) In most areas concrete takes advantages from the availability of the cheap raw materials.

9) A lower grade of skilled labor is required compared to the other materials.

At the same time concrete has the following disadvantages, (McCormac, 1985):

1) Concrete has a very low tensile strength.
2) Forms are required to hold the concrete in place until it hardens sufficiently.
3) The low strength per unit of volume of concrete means relatively large members.
4) The properties of concrete vary widely due to variations in its proportioning and mixing. Further more, the placing and curing of concrete is not carefully controlled as in the production of other materials.
5) Concrete does not have definite yield strength.
6) Corrosion and other pavement distress is expected to be developed when the concrete cracks distribute.

1.3 Statement of the Problem.

There is a critical need to improve the engineering properties of all material in general by a minimum cost, specially concrete, because of it's importance in the construction fields.

At the same time, despite of the huge expansions in construction works, there is a great increase in the raw-constructed materials prices. The following tables explain the demand increasing on reinforcement steel and aggregates, and the increasing in aggregate prices in Jordan.

Table (1.2). The Demand Increasing on Reinforcing Steel and Aggregates in Jordan. (Othman, 1989).

Material	Year			
	1980	1985	1989	1995
Reinforcing Steel (Thousand ton)	856.8	1192.8	1483.8	1632.2
Aggregate (Thousand cubic meter)	28755	40030	49798	54778

Table (1.3). The Increasing of the Aggregate Prices in Jordan, (JD/m^3). (Sharif et al, 1984 and Engineers, 1995).

Aggregate Size	Year				
	1960	1970	1980	1990	1995
(4.75- 25)mm	0.15	0.50	0.85	3.5	4.0
(0.6-12.5)mm	0.15	0.55	0.90	3.5	4.0

At the same time of the last discussed points, the environmental regulations are yearly increasing regarding waste materials. Beside a great efforts from many researchers try to reuse many of waste material specially in the construction field, in order to reduce its action in pollution and other environmental problems.

1.4 Objectives and Scope of the Study.

The major objective of the study will be to emphasize the concrete pavement importance to maintain the yearly increase of the heavy traffic load. Also an investigation of the concrete properties when the steel swarf is used with its mixes, and an estimation of the cost reduction that will be attempted, in order to solve the previous problems which is summarized as following:

- There is a critical need to improve the properties of concrete by a minimum cost.
- Despite of the expansion in the construction works, there is a yearly increase of the construction material prices.
- At the same time, huge quantities of the produced waste materials as saw dusts and mineral swarf can be rehabilitated in construction fields.

Steel swarf was wasted from many of steel industries at workshops and factories, especially in the industrial countries, which cause a great environmental problems.

It is logical and not strange to try to reuse the steel swarf with concrete to improve their properties, specially under the following given conditions, (McCormc 1985):

1) Steel and concrete bond together very well so there is no slippage between the two, and thus they will act together as a unit in resisting forces. The excellent bond obtained is due to the adhesion between the two materials.
2) Concrete can protect steel swarf from fire and corrosion.
3) There is no reaction between the two materials.
4) Both of them have similar rate of thermal expansion. Concrete and steel have an expansion factors of (0.1 – 0.13 x 10^{-5} and 0.12 x 10^{-5} / c

1.5 The Importance of the Study.

The importance of the study, if its assumption is accepted will be the following benefits:

- Engineering benefits by improving the concrete properties.
- Economical benefits by reducing the price of the concrete cubic meter.
- Environmental benefits by reusing steel swarf in concrete.

1.6 Study Organization.

This study consists of five chapters, which try to present the material as briefly as possible.

Chapter one was devoted to indicate the pavement types, concrete advantages and disadvantages, the study objectives and importance.

Chapter two was devoted to the literature review that tries to improve concrete properties and types.

Chapter three discussed the methodology procedures that carried out in the study, the used material properties, concrete properties, concrete experimental tests and their results.

In chapter four a statistical and economical analysis and discussion of the test results were presented.

Finally, all conclusions and recommendations were summarized in chapter five.

CHAPTER TWO

LITERATURE REVIEW

CHAPTER TWO

LITERATURE REVIEW

At the last few years, many researchers around the world started to investigate the ability to improve concrete properties by using the natural and artificial fibers and waste materials as swarf and sawdust. At the same time they discussed the benefits and the applications of these types of concrete.

Fairhall ***et al.*** **(1992)**, has successfully designed and is now operating a major cement encapsulation plant for treating magnox swarf, a reactive intermediate level waste. The quality of the product has been established by development work using a blast furnace slag-ordinary Portland cement matrix. The product stability is dominated by controlling the magnox metal corrosion reaction by using a low water content grout and powders according to the British Nuclear Fuels laboratory (BNFL).

Velasco ***et al.*** **(1994)**, has studied the feasibility of cast iron swarf utilization as a raw material in the powder metallurgy industry.

This work drives the possibility of making steel components from cast iron swarf powder. Cast iron swarfs have been used as a direct additive in the manufacturing of steel, without making any other preliminary processes different from the pulverization to the desired size distribution.

In order to get a steel composition, the cast iron swarf powder has been dilute in high purity iron powder to reduce the cast iron carbon content. It has been simplifying the possible reuse of swarfs in the processes already existing in powder metallurgy.

Kobzenko ***et al.*** **(1988)**, presented results about an investigation into the reaction of hydrogen with niobium and the structure and properties of powder produced from swarf using hydrogenation method. The structures and properties were evaluated by electron microscopy, weight measurement, hardness testing and sieve analysis for the particle sizes.

Nunnally (1985) and Atyeh ***et al.*** **(1998)**, classified concrete in the following types:

- Structural lightweight concrete, which has a unit weight less than (1922 kg/m^3), which obtained its lightweight by using lightweight aggregates such as, expanded shale, clay and slag.
- Insulating lightweight concrete, which has a unit weight of (240-1442 kg/m^3) and utilized for its thermal insulating properties. Aggregates frequently used for such concrete include perlite and vermiculite.
- Mass concrete, which is used in structures such as dams in which the weight of concrete provides most of the strength of the structures. Its unit weight is regular about (2400 kg/m^3).
- Heavy weight concrete, which is made with heavy aggregates such as barite, magnetite and steel punching, and used primarily for nuclear radiation shielding. Unit

weight of such concrete has range of (2884 - 6408 kg/m^3).

- No-slump concrete, which has a slump of (25 mm) and less, which is used for pipe lines bedding and inclined surfaces.
- Refractory concrete, which is suitable for high-temperature applications such as boilers and furnaces. The maximum allowable temperature for refractory concrete depends on the type of the used aggregates.

Levon and Sako (1990), suggested using some materials powder like pumicite, bentonite and fly ash in order to modify the workability of concrete to provide cohesive concrete which prevents segregation, and minimizes bleeding of water which minimizes the surface cracks.

Recommendations also have been presented to modify the surfaces abrasion resistance by using the fine materials of the hard aggregates like volcanic rock, and the iron swarf with concrete. Another recommendation has been presented about using the iron aggregate and iron swarf with concrete for some heavy construction of structures such as the radiation shielding, rays-room in the hospitals and the hydraulic footings.

Neville (1995), presented and indicated the following points:

- The pozzolanic additions such as crushed Pyrex glass or fly ash have indeed been found effective in reducing the penetration of the coarser aggregate particles.

- Reduction in bleeding is obtained by the addition of pozzolanas or aluminum powder.
- Concrete with polymers indicates good resistance depending on the type of the filler, cohesion of binder and adhesion to the filler, Use of steel fibers in the concrete improves resistance to caviation; combination with polymerization is also possible.
- The surface abrasion resistance may be increased if metallic or other hardeners such as silicon carbide, corundum, or ferrosilicon is used in the surface layer of concrete.
- Aluminum powder is also used in grout for post-tensioned concrete in order to ensure complete filling of the cavity by the expanding grout. Powdered zinc can also be used.
- Using the ordinary Portland cement with a natural heavy aggregate and iron ore like magnetite, limonite, hematite and goethite can produce a special type of concrete, to provide the requirements of the radiation shield which includes:

1) Shields material, which has to be of high density to absorb the rays.
2) Shields material, which has to attenuate neutrons rays which mean containing heavy material.
3) Concrete used in shielding must also has good structural properties under high temperature conditions.

- Nailing concrete, which may be achieved by using sawdust as aggregate as a material into which nails can be driven in which they are firmly held. Other wood waste such as splinters, and shavings suitably treated chemically, have also been used to make non-load-bearing concrete with a density of (800-1200 kg/m^3).

Keer (1989), presented a complete study about fiber reinforced concrete. He applied several tests using a steel fibers of 0.0%, 1%, 2% and 3% to investigate the mechanical properties of the fiber reinforced concrete under variable stresses such as flexural strength, compressive strength, fatigue, impart forces, etc.

Concrete reinforced by steel fibers was studied and discussed deeply by him. He mentioned the old and new methods of the steel fibers production from the normal steel, and also from the stainless steel to prevent corrosion.

Keer also concluded the following points:

- Workability can be improved to a specific limits depending on steel fiber content in concrete.
- Moderate increase in the direct tensile strength of concrete can be obtained by using of steel fibers in concrete.
- Steel fibers can't cause any increase in concrete compressive strength.
- Steel fibers cause a good and positive modification in concrete flexural strength.

The following applications for steel fibers reinforced concrete were also discussed by him:

1) Highways and airfields pavements, depending on its flexural strength.

2) Hydraulic structures depending on its capacity in resisting abrasion and cavition.

3) Fibrous shotcrete: steel fibrous shotcrete is a mortar or concrete containing steel fibers pneumatically projected at high velocity onto a surface. The addition of steel fibers to shotcrete has considerably improved the flexural strength, direct tensile strength, shock resistance, ductility and failure toughness.

4) Special concrete for high thermal stresses depending on its capacity in crack control.

5) Precast concrete to produce some sensitive parts such as machine footings, and concrete pipes.

Swamy (1989), who outlines the following possibilities, has reviewed the prospects for the use of fiber reinforcement in structural applications:

- Fiber reinforcement can inhibit crack growth widening, which may permit the use of high-strength steel without excessive crack widths or deformation at service loads.
- The use of fiber reinforced concrete has been applied to hemispherical domes, using an inflated membrane process.
- Fiber reinforcement can act effectively as shear reinforcement. Punching shear strength of slabs may be increased and sudden punching shear failure transformed into a slow ductile one.
- In prestressed concrete members, the addition of fiber reinforcement has been found to reduce

transmission lengths and prestress losses due to elastic shortening, shrinkage and creep.

- Fiber reinforcement can provide increased impact strength for conventionally reinforced beams. Resistance to local damage and spalling is also increased.
- Fiber reinforcement can provide enhancement and integrity to preserve conventionally reinforced concrete structures subject to earthquake and explosive loading.

Abu Deyya (1986), has studied the use of fibers in reinforced concrete columns. By the tests of axially loaded specimens, he observed that the ductility increased slightly with the increase in the amount of fibers.

The fibers need to be placed in the outer cover of the column in order to help in confining the concrete core. Applying of high shearing forces and axial loads simultaneously to restrained short columns under double curvature bending, cause an unfavorable explosive type of failure. Proper proportioning of the column dimensions can control this type of failure. The use of fibers helps in reducing such violent failure.

He indicated that by using of fibers in the columns, the failure behavior changed from an explosive type to a bending type of failure. The shear capacity was increased with a less explosive type of failure occurring.

Al-Far (1988), carried out several tests on reinforced uncured concrete beams with steel fibers, exposed to local environment in Amman, Jordan to investigate the behavior of these beams in shear and the effect of steel fibers on curing and cracking. The tests were applied on 15 simply supported rectangular reinforced concrete beams under two point loading with five different percentage fraction of steel fibers of 0.0%, 0.5%, 0.75%, 1%, 1.5% of total weight.

During the tests strains, deflections, first crack load and ultimate load in shear, cracking and its propagation are recorded for the cured and uncured beams without fibers and uncured beams with fibers.

The tests results indicated that what is lost in shear and tensile strength of concrete due to exposure to local environment without any curing, which is likely to encounter in practice in desert and arid regions, due to non-availability of water, can be gained by inclusion of one percentage of steel fiber by weight of concrete in uncured reinforced concrete beams. Which is nearly the same strength in shear and in tension as conventional reinforced concrete beams cured under ideal laboratory environment.

Abu-Ghazleh (1990), studied the behavior in bending, cracking, deflection, deformation and crack propagation of uncured reinforced concrete beams with steel fiber. The tests were carried out on reinforced uncured concrete beams, with steel fibers exposed to local environment in Amman, Jordan.

These beams contained five different percentages of steel fibers of 0.0%, 0.5%, 0.75%, 1% and 1.5% of total weight.

During the test, strains, frust crack load and ultimate load in flexural, cracking and its propagation were recorded for the cured and uncured beams without fibers and the uncured beams with fibers.

The results indicated that what is lost in flexural strength and stiffness due to no curing or improper condition was gained by inclusion of 0.5% fiber by weight of total mix.

Awdat (1991), presented an experimental study, which was carried out to investigate some properties of steel fiber reinforced, foamed concrete.

These properties include workability, compressive strength and splitting tensile strength of hardened concrete. A total of 90 mixes were made with variable steel fibers contents of 0.0%, 0.487%, 0.95%, 1.391% and 1.811% by total weight.

Evaluation is made concerning effect of steel fiber on workability, compressive strength and splitting tensile strength. The results indicated the followings:

- The spread of steel fiber in reinforced foamed concrete mixes is useful in controlling the segregation. The addition of 0.95% volume fraction yields an optimum degree of consistency. Steel fibers volume fraction more than 0.95% increase the spread reduction and the mixes to stiff consistency and then to be not workable and segregation take a place.
- The addition of steel fibers to foamed concrete improves the compressive strength in average of (25-60)% compared to mixes without steel fibers.

- Also, the addition of steel fibers enhances the splitting tensile strength of steel fiber reinforced foamed concrete in the range of (160-225)% as compared to mixes without steel fibers.

Bayasi ***et al*** **(1992)**, discussed the mechanism of action of fibers in concrete. For fibers with small diameters (carbon, cellulose, polyester, kevlar and others), in the range of 10-30 microns, microcrack arrest mechanism is the dominant fiber action. Upon incorporation of fibers at typical volume fraction (0.5-7)%, a very large number of small diameter inclusions is distributed throughout the cementitious matrix. This is termed as high fiber count situation that results from the very small volume of individual fibers. The probability of a fiber crossing a concrete matrix microcrack is considerably high and, thus, the matrix tensile strength is significantly increased. This increase is caused by fiber delay of microcrack propagation, which generally initiates failure.

The case of fibers with large diameters (steel and polypropylene), greater than 0.1 mm, is mainly characterized by macrocrack arrest phenomenon. The relatively small fiber count of large diameter fibers reduces the possibility of crossing microcracks with fibers. However, upon the formation of a macrocrack, fibers extend across the crack leading to an increase of matrix failure ductility and a moderate increase in tensile strength.

Ghosheh (1995), studied the shear capacity of steel fiber reinforced concrete beams.

A total of 18 steel fiber reinforced concrete beams were tested. Test results are presented on the shear strength of tested beams in which the shear span to depth ratio (a/d: 2, 2.5, 3 and 3.5), volume fraction of steel fibers (v_f, 0.0, 0.375, 0.5, 0.7, 1 and 1.25) were the main variables. Test results indicated that the steel fibers had significant influence on the mode of failure and ultimate shear strength of longitudinally reinforced concrete beams.

Conventional reinforced concrete analyses with some modification, as suggested in this study to account for the effect of fibers content, gave good predictions of the ultimate strength for rectangular beams without shear reinforcement.

The previous discussion indicates the followings:

- Some researchers succeeded in reusing the iron swarf in the industry of the cement and the steel itself.
- Other researchers recommended using the powders of some materials to improve the concrete workability and its properties in the hardened form.
- Many researchers succeeded in improving the concrete properties by using the steel fibers in its mix.
- Accordingly, it would be useful to investigate the affect of the waste materials such as the steel swarf on the concrete properties.

CHAPTER THREE

METHODOLOGY AND RESULTS

CHAPTER THREE
METHODOLOGY AND RESULTS

3.1 Introduction

In order to achieve the objectives of the study, serial procedures of experimental and theoretical investigations, which are shown in figure (3.1) were carried out. These procedures initiated by specifying the requirements of road concrete, then set of tests and investigations on local concrete mixtures (cement, water, aggregate, sand and iron swarf) were applied to provide a strong and durable concrete mix.

Then a concrete mix design depending on these material properties was prepared to maintain roads concrete conditions and requirements.

The last stage of these followed procedures was a group of the following experiments applied on a standard specimen in order to check the goodness of the study assumption:

- Fresh concrete experiments, which include slump depth, Kelly ball and compacting factor tests.
- Hardened concrete experiments, which include cubes and cylinders compression, cylinders splitting, beam flexure, density and rebound hammer tests.
- Concrete durability experiments, which consist of water and air permeability and skidding for concrete.

In the following sections these procedures and experiments are discussed briefly.

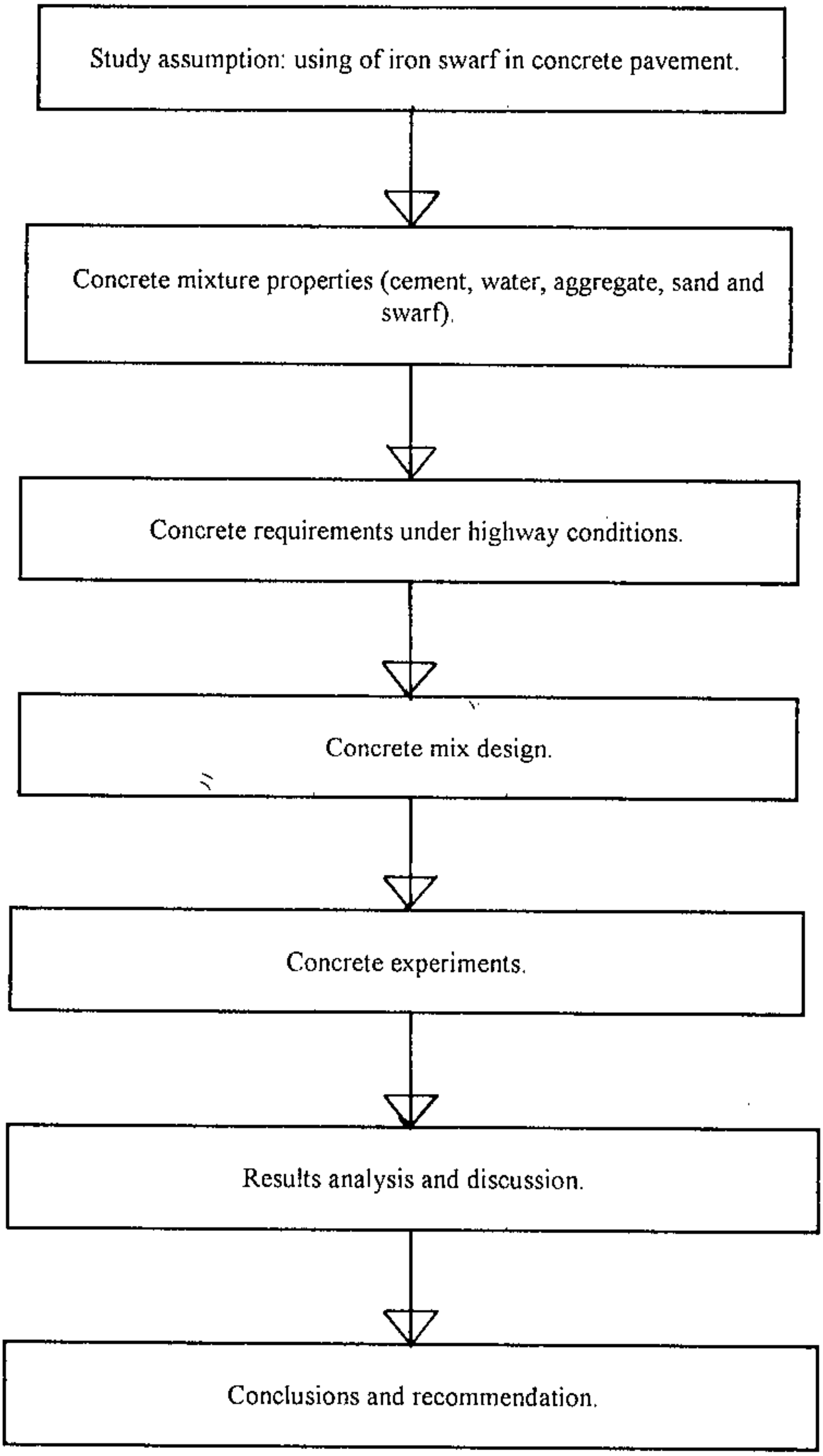


Fig (3. 1). Study Methodology Flow-Chart.

3.2 Materials Properties.

Local Jordanian materials were used, namely: Local produced cement, Sweileh sand, Lime stone aggregates potable water and iron (steel) swarf.

In this section the material and their relevant properties were studied and specified.

3.2.1 Cement

Cement paste is the active component of concrete that has the following main functions:

- To fill the voids between the particles of the inert aggregates, providing lubrication of the fresh, plastic mass and water tightness in the hardened product.
- To give strength to the concrete in its hardened state, as a binder material.

The type of concrete has a significant effect on the rate of hydration and the rate of strength development; therefore, the type and quantity of cement greatly affects the concrete quality. (Ghadieh, 1993).

Ordinary portland cement is the binding material most often used in concrete roads slabs, but where a high early strength is required, so that a road can be opened to traffic earlier than is usual, a rapid hardening is required. In certain instances, as for example where it is desired to define a particular traffic lane, colored cement are utilized. (Flaherty, 1978).

The type of cement used in this research is the ordinary portland cement produced locally according to the British Standards (BS: 12/91), because it is the most available and commonly used in Jordan.

The physical properties of this cement type and chemical composition according to the Royal Scientific Society characterization are as followings:

Table (3.1). Chemical Composition and Properties for Ordinary Portland Cement.

Sio_2	20.85%
Cao	60.95%
Al_2O_3	4.06%
Fe_2O_3	3.2 %
So_3	2.82%
Mgo	1.21%
K_2O+Na_2O	0.65%
Loss on ignition	3.6
Insoluble material	1.82
Moisture content	0.6

-Specific gravity 3.15

-Specific surface 3954 cm2/gm.

-Initial set 138 minutes.

-Final set 5-6 hours.

3.2.2 Water

Water is used in the concrete mixing to over come the aggregate absorption, complete cement reaction and provides the adequate workability. It is usually used as a ratio from the cement weight, depending on the required strength of concrete.

In most instances the specifications simply prescribe that the water should be potable. This requirement is normally sufficient to insure that the water does not contain any impurities that will affect on the cement paste quality.

Generally potable water must be clean, and free from harmful amounts of alkalis, acids, and organic matters, also salty water which causes corrosion prevented in reinforced concrete, and steel fibers concrete. (Ghosheh, 1995).

Therefore, the mixing water used in preparing the study specimens is the normal potable water in Amman.

3.2.3 Aggregate Properties and Tests

3.2.3.1 Introduction

Aggregates that provide about three-quarters of the concrete's body, therefor its properties have a great effect on the concrete properties.

The aggregates in concrete have following three principal functions:

- To provide a relatively cheap filler for the cementing material.
- To provide a mass of particles which are suitable to resisting the action of applied stresses (loads, abrasion, thermal, etc).
- To reduce the volume changes resulting from the setting and hardening process in the cement paste. (Ghadieh, 1993).

The properties of concrete resulting from the use of particular aggregates depend upon:

1. The mineral character of the aggregate particles, particularly as related to the elasticity strength, and durability.
2. The surface characteristics of particles, which is related to workability of fresh concrete, and bond within the harden mass.
3. The grading of the aggregates, particularly as related to the workability, compatibility, density, and economy of the mix.
4. The amount of aggregate in unit volume of concrete, particularly as related to cost and volume changes due to drying. (Ghadieh, 1993).

3.2.3.2 Aggregate Properties and Tests

High quality aggregate consists of particles, which are free from fractures, and not flat or elongated, which do not slake when wetted and dried. Their surface texture is relatively rough with little or no unfavorable absorption. (Khreisat, 1994).

Aggregate properties have many variables to be considered in the investigation. Maximum size, shape, gradation type, and mineralogy are the most important factors that affect the following aggregate properties:

- Bulk unit weight.
- Specific gravity.
- Abrasion resistance.
- Absorption of water.
- Aggregate gradation.

The local aggregate from Amman was used, and its properties were tested, and summarized as followings:

- The fine aggregates used was Sweileh sand and their properties according to the British Standard (BS:812) are:

1) Dry density = 2.6
2) Saturated surface density = 2.64
3) Water absorption = 1.52%
4) Bulk unit weight = 1.875

- The coarse aggregate used were crushed line stone and their properties according to the British Standard (BS:812) are:

1) Dry density = 2.49
2) Saturated surface density = 2.57
3) Water absorption = 2.89%
4) Bulk unit weight = 1.53

Also, abrasion resistance of the coarse aggregate was estimated by Los Angeles machine and according to (ASTM-C-131) and its equal 34%.

Gradations for fine and coarse aggregate were conducted according to the British Standard (BS: 882). These gradations were compared with The Jordanian Standard Specifications (J.S.S.) limits in tables (3.2 and 3.3). Also, figure (3.2 and 3.3) show graphically the gradation of fine and coarse aggregate compared to The Jordanian Standard Specifications (J.S.S.) limits.

Table (3.2) and figure (3.2) show that the gradation of the coarse aggregate sample provides the Jordanian Standard Specifications (J.S.S) requirements at sieve sizes of (3/4", 3/8" and No.7), but it exceeds the upper limits at sieve size of (3/16").

Table (3.3) and figure (3.3) show that the gradation of the fine aggregate sample aligns the Jordanian Standard Specifications (J.S.S) at sieve number of (7, 14, 25 and 100), but it simply exceeds the upper limits at sieve number (52).

Table (3.6) and figure (3.8) show the gradation of a suggested mix of one unit weight fine aggregate with two unit weight of the coarse aggregate and indicate that the suggested mix is completely align the Jordanian Standard Limit.

Table (3.2). Coarse Aggregate Gradation.

Sieve No. (BS)	Percentage passing by weight of the Specimen (%)	Jordanian Standard specifications limits (J.S.S) (%) (Jordanian Standard, 1993)
3/4 inch (19.0 mm)	100	95-100
3/8 inch (9.52 mm)	52	20-55
3/16 inch (4.76 mm)	22	0-10
No. 7 (2.4 mm)	6	0-5

Table (3.3). Fine Aggregate Gradation.

Sieve No. (BS)	Percentage passing by weight of the Specimen (%)	Jordanian Standard Specifications limits (J.S.S) (%) (Jordanian Standard,1993)
No. 7 (2.4 mm)	100	75-100
No. 14 (1.2 mm)	84	55-90
No. 25 (600 micrometer)	60	35-59
No. 52 (300 micrometer)	33	8-30
No. 100 (150 micrometer)	7.5	0-10

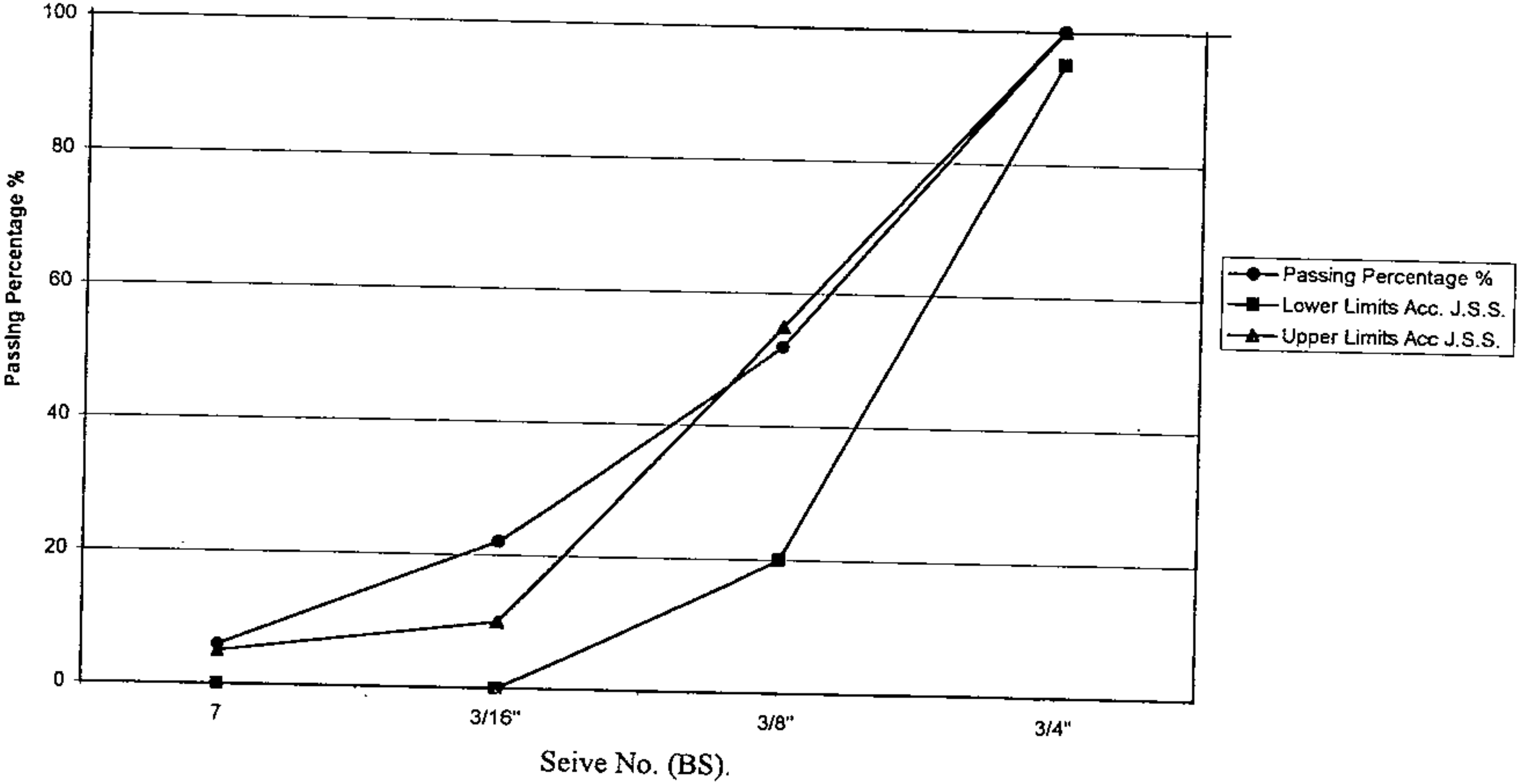


Fig (3.2). Coarse Aggregate Gradation.

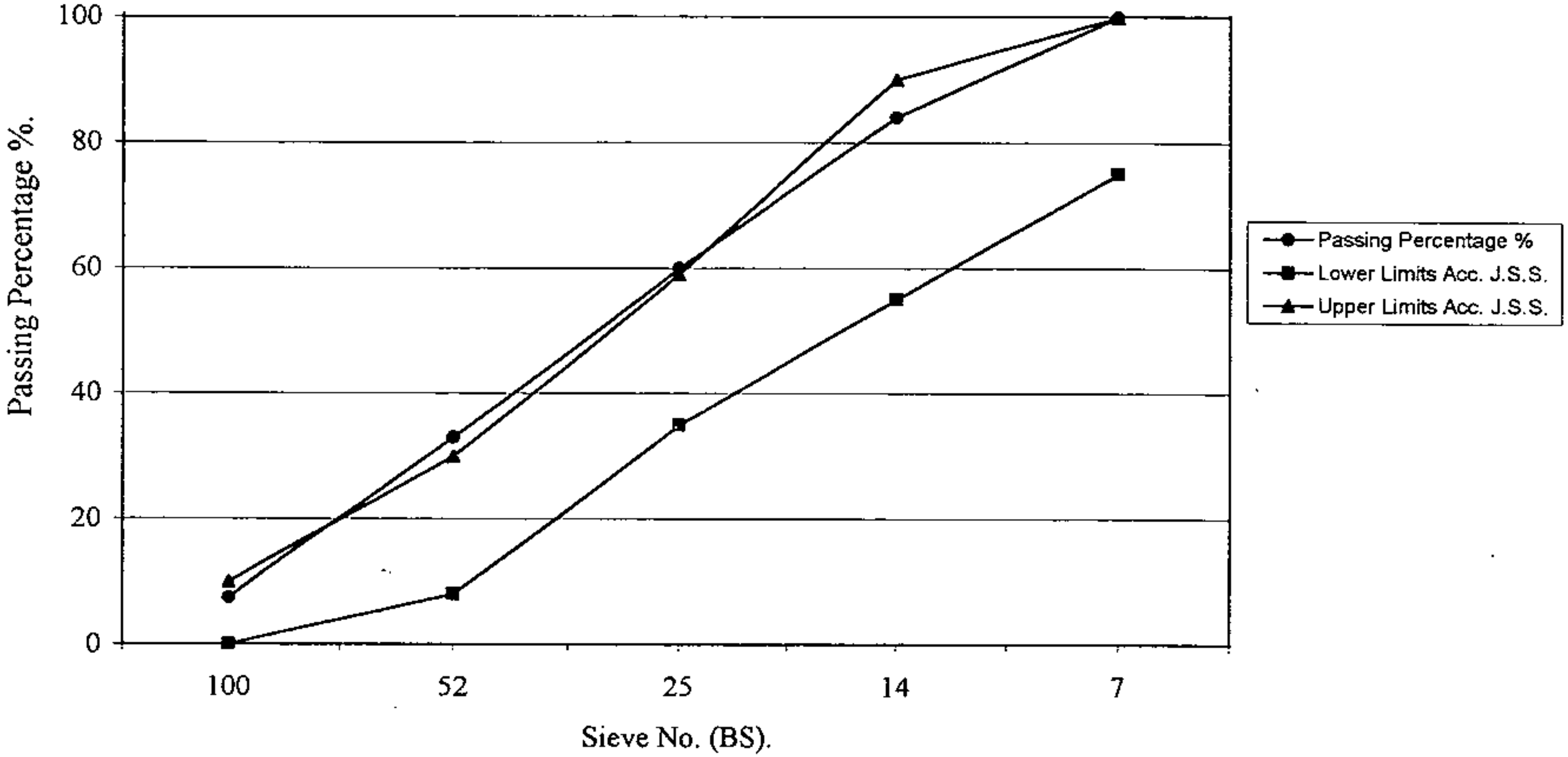


Fig (3.3). Fine Aggregate Gradation.

3.2.4 Iron (Steel) Swarf

Swarf wasted from the steel industries at workshops and factories was used. It is reported that the steel from which the swarf was produced has the following properties:

- Yields stress 24 kg/mm^2.
- Ultimate stresses 35 kg/mm^2.
- Minimum elongation 20%.

The swarf itself has the following gradation according to the British Standards (BS: 882):

Table (3.4). Steel Swarf Specimen Gradation.

Sieve No. (BS)	Retained Percentage (%)	Accumulative Passing Percentage (%)	Accumulative Retaining Percentage (%)
14	1.33	98.67	1.33
25	8.7	89.97	10.03
52	34.3	55.67	44.33
100	32.7	22.97	77.03
200	20.3	2.97	97.03
			229.75

- Fineness modulus = (229.75/100) = 2.29
- Maximum particles size = 2.4 mm.

Also, figure (3.4) shows the swarf particles gradation graphically.

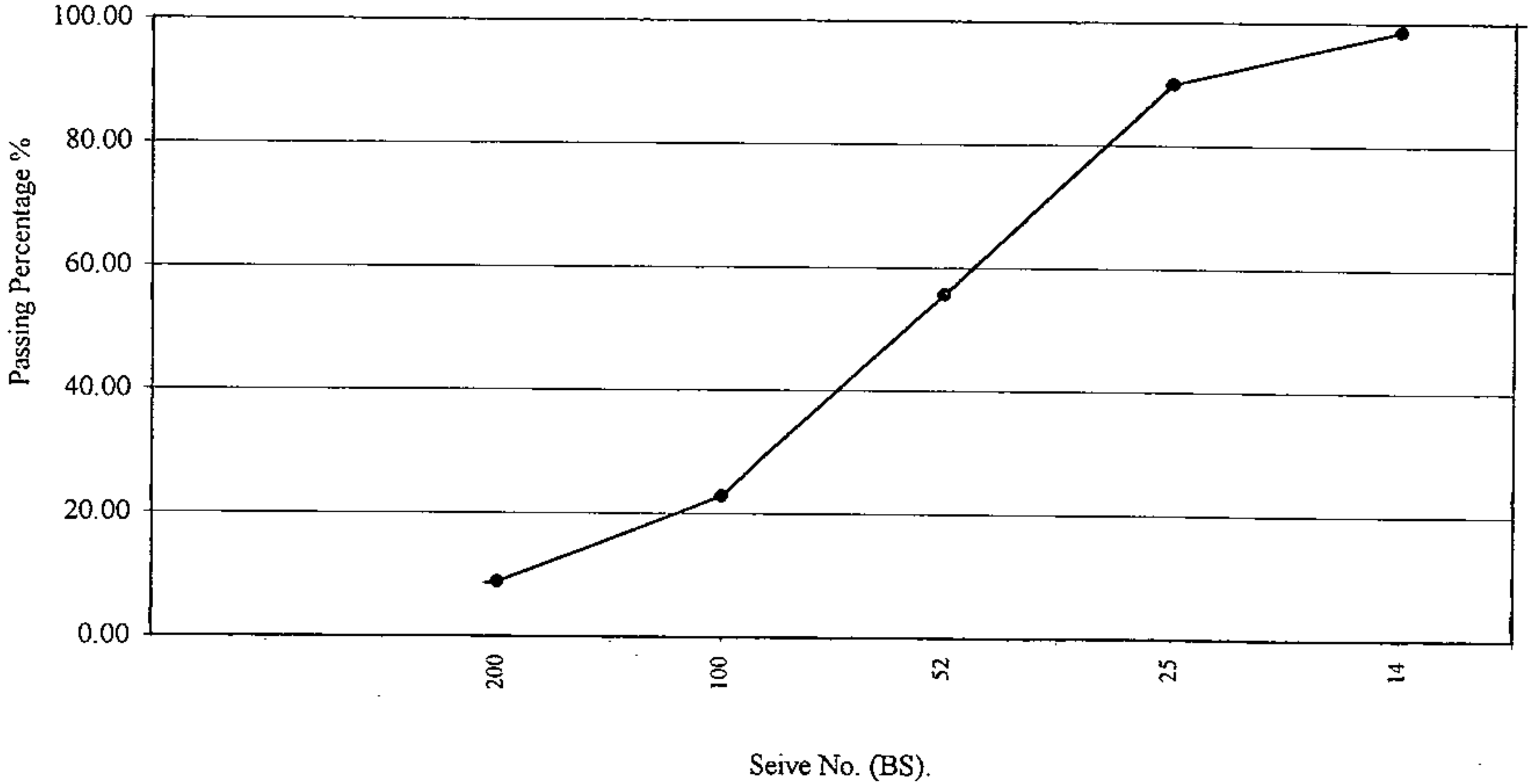


Fig (3.4). Swarf Gradation.

3.3 Concrete Mix Design, Requirements and Proportioning.

3.3.1 Preface and Definition

The required properties of hardened concrete are specified by the designer of the structure (pavement), and the properties of the fresh concrete are governed by the type of construction and by the techniques of mixing, placing and transporting.

These tow sets of requirements enable the engineer to determine the composition of the mix, bearing in mind the degree of control exercised on the site.

Mix Design can then be defined as the process of selecting suitable ingredients of concrete and determining their relative quantities with the object of producing as economically as possible concrete of certain minimum properties, notably consistence, strength and durability. (Neville, 1995).

3.3.2 Basic Considerations.

Mix design process depend on the following factors:

- Although it takes water to initiate the hydraulic reaction, the higher the water-cement ratio, the lower the resulting strength and durability, see figure (3.5).
- The more water that is used the higher will be the slump.
- The more aggregate that is used the lower the cost of concrete.
- The more the concrete is consolidated the better it becomes.

- The larger the maximum size of coarse aggregate, the less the amount of cement paste that will be needed to coat all the particles and provide necessary workability.
- The surface skidding and abrasion resistance of the concrete is almost entirely a function of the properties of the fine aggregate. (Peurifoy, 1985).

Also the Basic Factors in Mix Design Process are shown in figure (3.6).

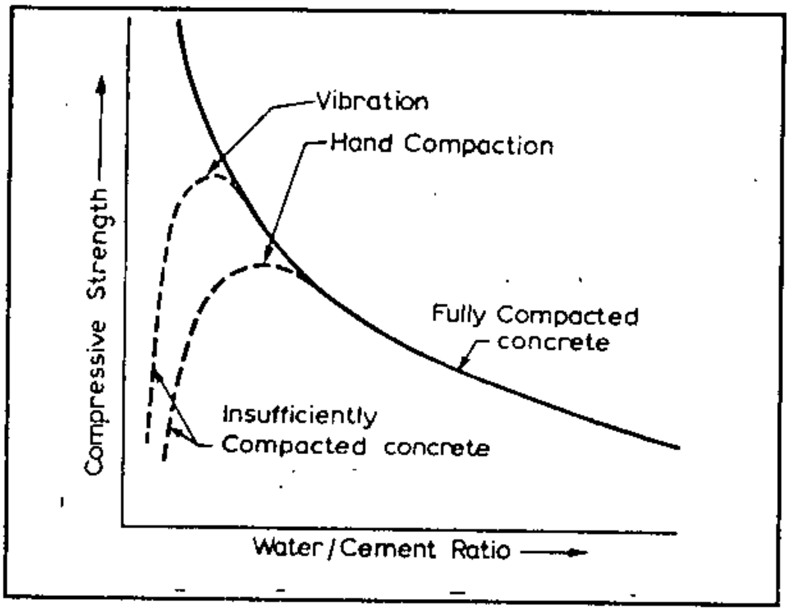


Fig (3.5). The Relation between Strength and Water-cement Ratio of Concrete. (Leavon and Sako, 1990).

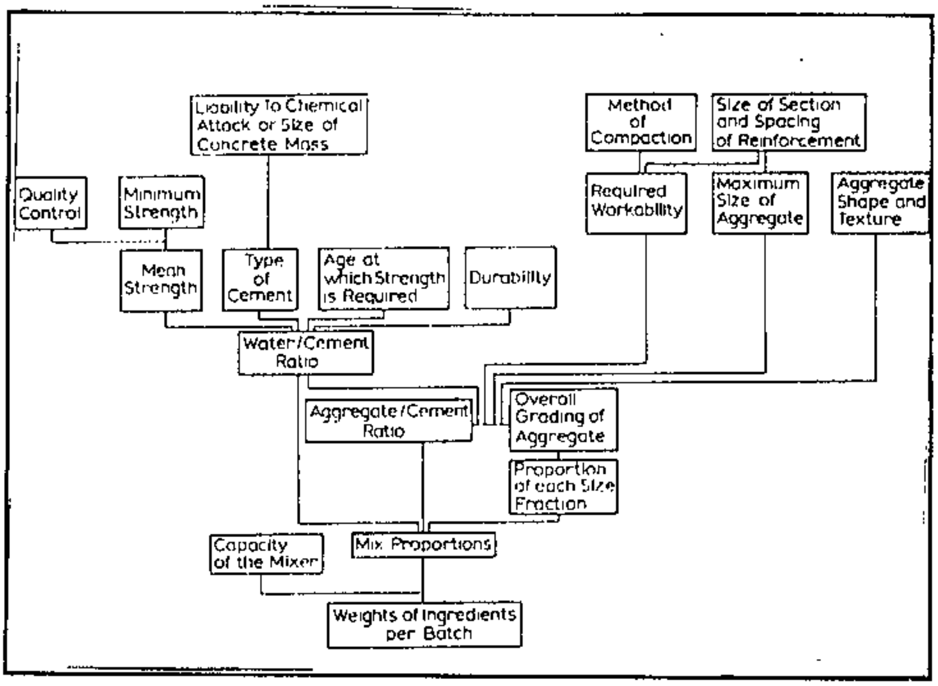


Fig (3.6). Basic Factor in Mix Design Process. (Neville, 1995).

3.3.3 Roads Concrete Requirements.

According to the British Road Research Lab requirements, concrete used in road construction is normally required to have a compressive strength of more than (270 kg/cm^2) after 28 days.

This material usually has flexural strength of more than (30 kg/cm^2), that indicates it has significant beam strength. Its modulus of elasticity in the order of (3.45x10^5 kg/cm^2), which means that concrete slab must have a high degree of rigidity. It must have a minimum quantity of cement of (335 kg/m^3) and a slump of (25-75 mm). (Flaherty, 1978).

3.3.4 Proportioning.

3.3.4.1 Concrete Mix Design.

Depending on the British Road Research Laboratory method that explained in the Road Note No (4) and denoted by Flaherty (1978), a mix design was prepared to maintain the materials properties discussed in section (3.2), and the roads concrete requirements explained in section (3.3.3). The following steps summarize this design:

Step 1:

To allow the normal variation in concrete strength, the required mix design strength (270 kg/cm^2) must be increased. So by using of table (3.5) and assuming strict control for roads paving works, the minimum strength may be expected to be (75 percent) of the average strength. Thus the average strength to be aimed at in mix design is 270x(100/75) = (360 kg/cm^2).

Table (3.5). Estimated Relation between the Minimum and Average Crushing Strengths of Works Cubes for Different Works Conditions. (Neville, 1995).

Conditions	Minimum strength as percentage of average strength
Very good control with weight batching, use of graded aggregates, moisture determinations on aggregates, etc. Constant supervision.	75
Fair control with weight batching. Use of tow sizes of aggregate only. Water content left to mixer-driver's judgement. Occasional supervision.	60
Poor control; inaccurate volume batching of all-in aggregates. No supervision.	40

Step 2:

By using figure (3.7) the required strength of a (360 kg/cm^2) can be attained by a water-ordinary portland cement ratio of (0.5).

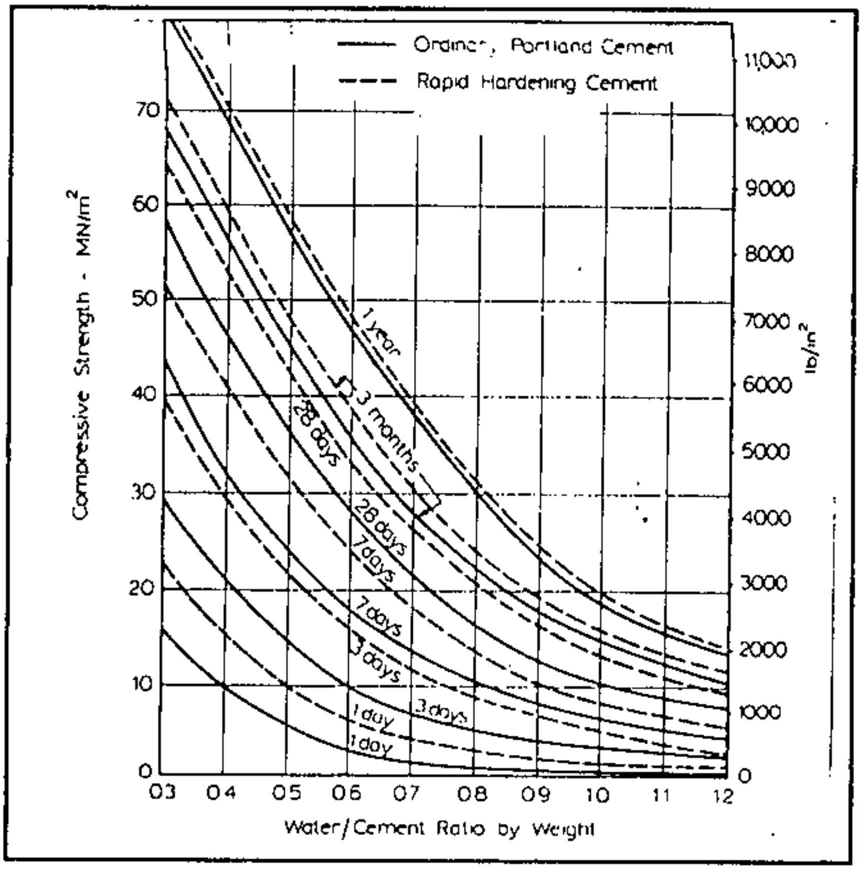


Fig (3.7). Relation between Compressive Strength and Water-cement Ratio for Cubes of Fully Compacted Concrete for Mixes of Various Proportions. (Neville, 1995).

Step 3:

a) An assumption of low workability that has of (25-50 mm) depth is suitable for the purpose of road paving.

b) Also a primary suggestion of coarse to fine aggregate ratio of (2) by weight indicated that the mixture gradation will provide the Jordanian Standard

Specifications limits, and the British Road Research Laboratory method requirements. Table (3.6), figure (3.8) and figure (3.9), explain the goodness of the last assumption and indicate that the suggested mixture gradation align to No. (3) grading, that suggested by for the aggregate of (19 mm) maximum size.

Table (3.6). The Suggested Mixture Gradation.

Sieve No. (BS)	Passing Percentage for the Specimen (%)	Jordanian Standard Specifications limits (%) (Jordanian Standard, 1993).
3/4"	100	70-100
3/8"	68	50-75
3/16"	48	35-60
No. 7	37	27-45
No. 14	28	20-35
No. 25	20	12-25
No. 52	11	5-15
No. 100	2.5	1-5

Step 4:

By using of table (3.7), the aggregate to cement ratio (A/C) that will be suitable to provide the previous requirements. and the use material properties will be (A/C = 4.5) by weight.

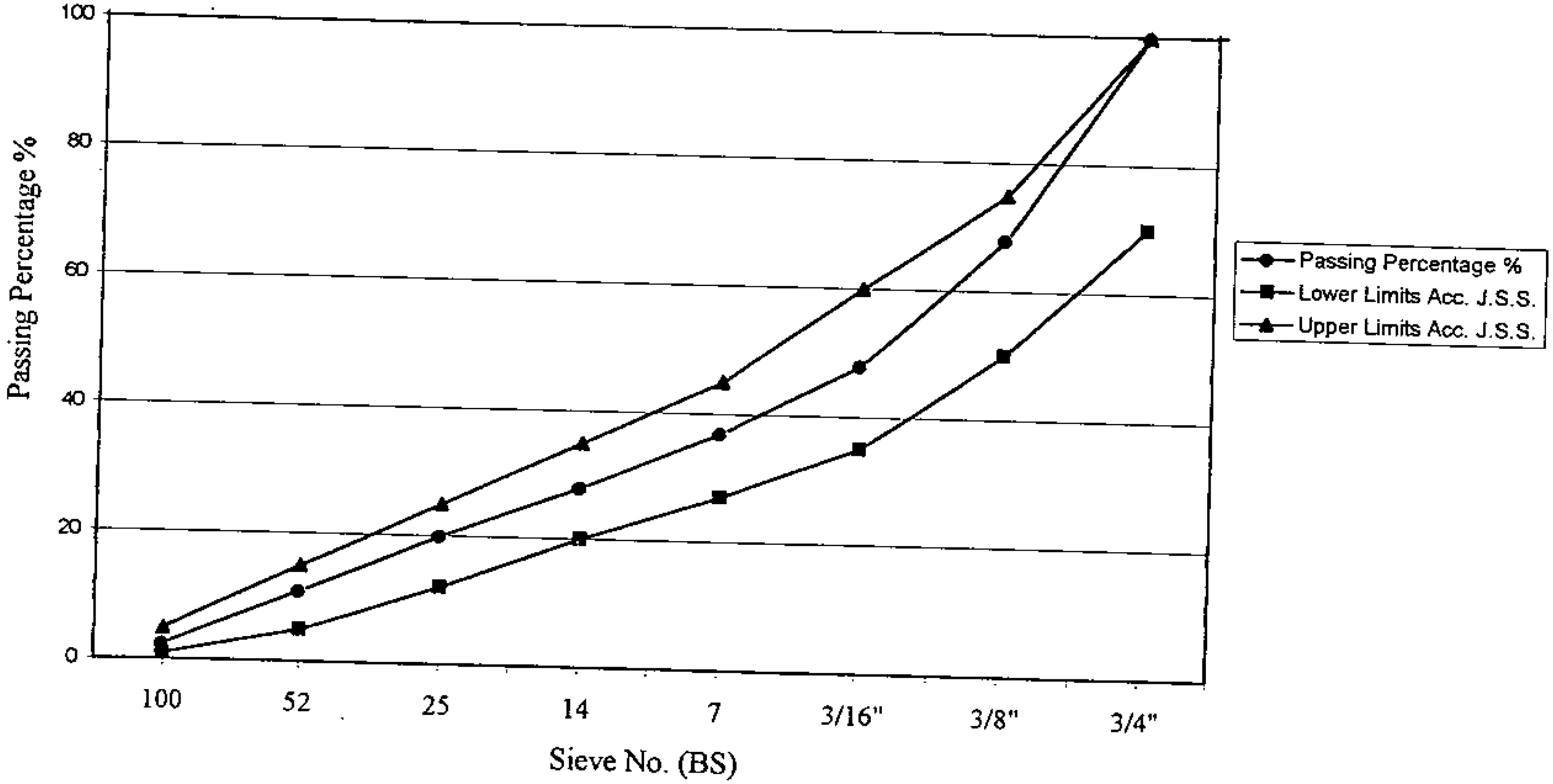


Fig (3.8). The Suggested Mixture Gradation.

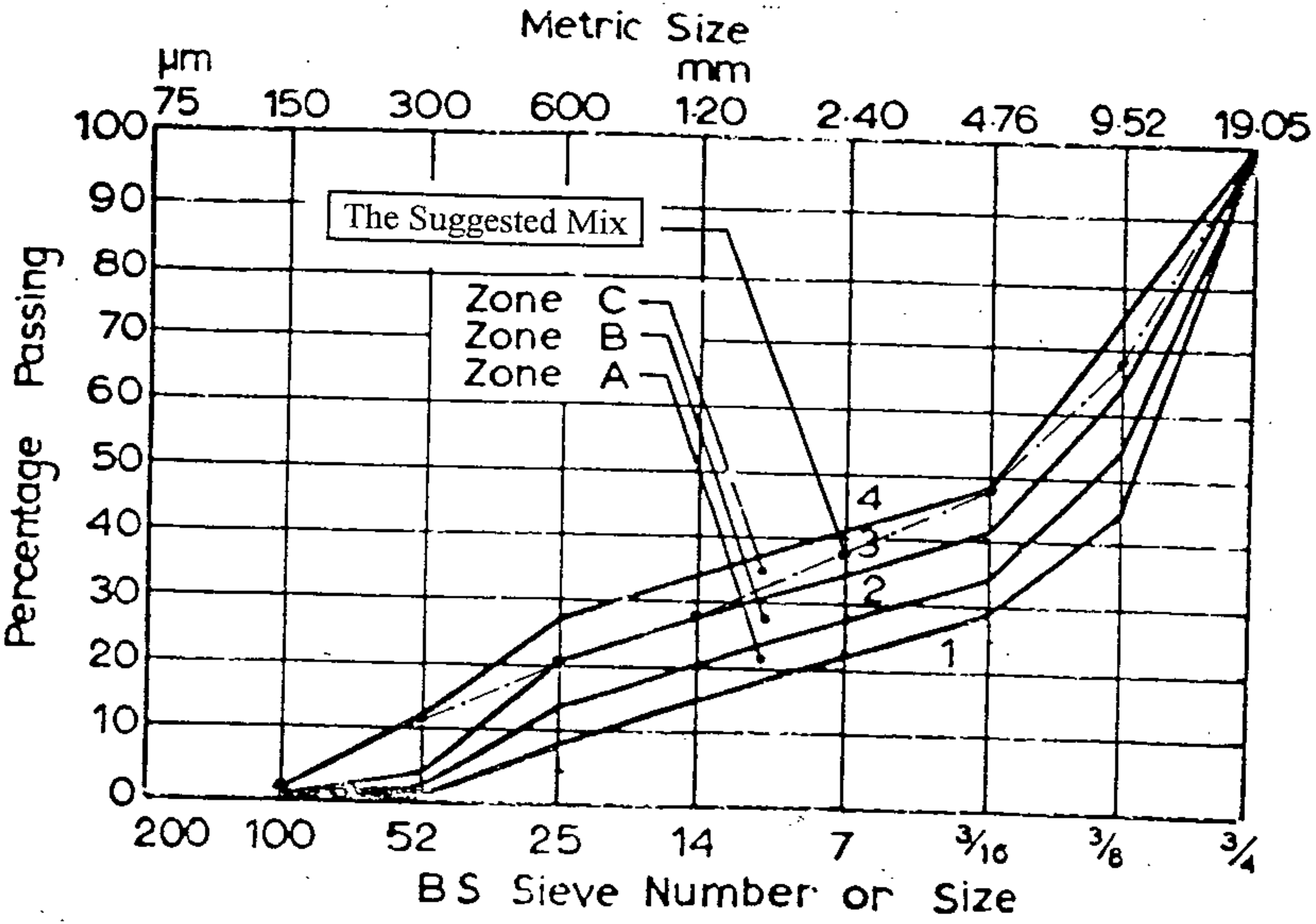


Fig (3.9). Concrete Aggregate Curves According to (B.R.R.L).

(Neville, 1995).

Table (3.7). Aggregate:cement Ratio Required to Give Four Degree of Workability With Different Grading of (19 mm).

(Neville, 1995).

Degree of workability		*Very low*				*Low*				*Medium*				*High*			
Grading of aggregate (curve no. on Fig. 8.1(a))		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Water:cement ratio by weight	0·35	3·2	3·0	2·9	2·7	2·7	2·7	2·5	2·4	2·4	2·4	2·3	2·2	2·2	2·3	2·1	2·1
	0·40	4·5	4·2	3·7	3·5	3·5	3·5	3·2	3·0	3·1	3·1	2·9	2·7	2·9	2·9	2·8	2·6
	0·45	5·5	5·0	4·6	4·3	4·3	4·2	3·9	3·7	3·7	3·7	3·4	3·3	3·5	3·5	3·2	3·1
	0·50	6·5	5·8	5·4	5·0	5·0	4·9	4·5	4·3	4·2	4·2	3·9	3·8	×	3·9	3·8	3·5
	0·55	7·2	6·6	6·0	5·6	5·7	5·4	5·0	4·8	4·7	4·7	4·5	4·3	×	×	4·3	4·0
	0·60	7·8	7·2	6·6	6·3	6·3	6·0	5·6	5·3	×	5·2	4·9	4·8	×	×	4·7	4·4
	0·65	8·3	7·8	7·2	6·9	6·9	6·5	6·1	5·8	×	5·7	5·4	5·2	×	×	5·1	4·9
	0·70	8·7	8·3	7·7	7·5	7·4	7·0	6·5	6·3	×	6·2	5·8	5·7	×	×	5·5	5·3
	0·75	—	—	8·2	8·0	7·9	7·5	7·0	6·8	×	×	6·2	6·1	×	×	5·8	5·7
	0·80	—	—	—	—	—	—	7·4	7·2	×	×	6·6	6·5	×	×	6·1	6·0
	0·85					—	—	7·8	7·6	×	×	7·1	6·9	×	×	6·4	6·3
	0·90					—	—	—	—	×	×	7·8	7·3	×	×	×	6·7
	0·95									×	×	8·0	7·6	×	×	×	7·0
	1·00									×	×	—	—	×	×	×	7·3

Angular aggregate e.g. crushed rock

- Indicates that the mix was outside the range tested.

× Indicates that the mix would segregate.

Step 5: A trail mix was made up and it could be noted that the average cube compressive strength of the no swarf concrete was higher than the specified compressive strength of 270 kg/cm^2.

Step 6: Finally the mix design proportions that accept and maintain the roads concrete requirements, and the properties of the available materials for the study were summarized as following:

- Slump depth (25-50 mm).
- Water:cement ratio (W/C) = (0.5) by weight.
- Aggregate:cement ratio (A/C) = (4.5) by weight.
- Fine:coarse aggregate ratio = (0.5) by weight.

3.3.4.2 The Iron (Steel) Swarf Proportions.

The steel swarf was used with concrete by a five percentages of concrete mixtures weight; (0.0, 0.85, 1.7, 2.55, 3.4) %. The selection of these percentages depended on several previous studies related to the use of steel fibers in concrete such as: (Al-Far, 1988), (Keer, 1989), (Abu Ghazleh, 1990), (Awdat, 1991), (Bayasi, 1992), and (Ghosheh, 1995), which were discussed earlier in chapter two.

3.3.5 Mixing Procedure.

Mixing of the mixtures was done in a rotary mixer in which cement, sand and coarse aggregates were thoroughly mixed. The required amounts of water were then added. After 2 minutes of initial mixing, the steel swarf was gradually spread over the fresh concrete and mixing continued until a homogeneous mix was obtained, and then used to prepare 3 specimens at each swarf content for testing fresh and hardened concrete with number of 130 sample as shown in figure (3.10).

3.4 Concrete Properties, Behavior and Testing.

3.4.1 Introduction.

Concrete properties, and behavior affected by its material properties, and proportioning; also it depends on the surrounding conditions.

These properties include fresh concrete workability, hardened concrete strength, and concrete durability.

In order to investigate the assumed objectives of the study, set of tests were applied on an adequate number of specimens with a five different percentages of steel swarf in order to study the last properties of concrete, figure (3.10) shows the tests flow-chart.

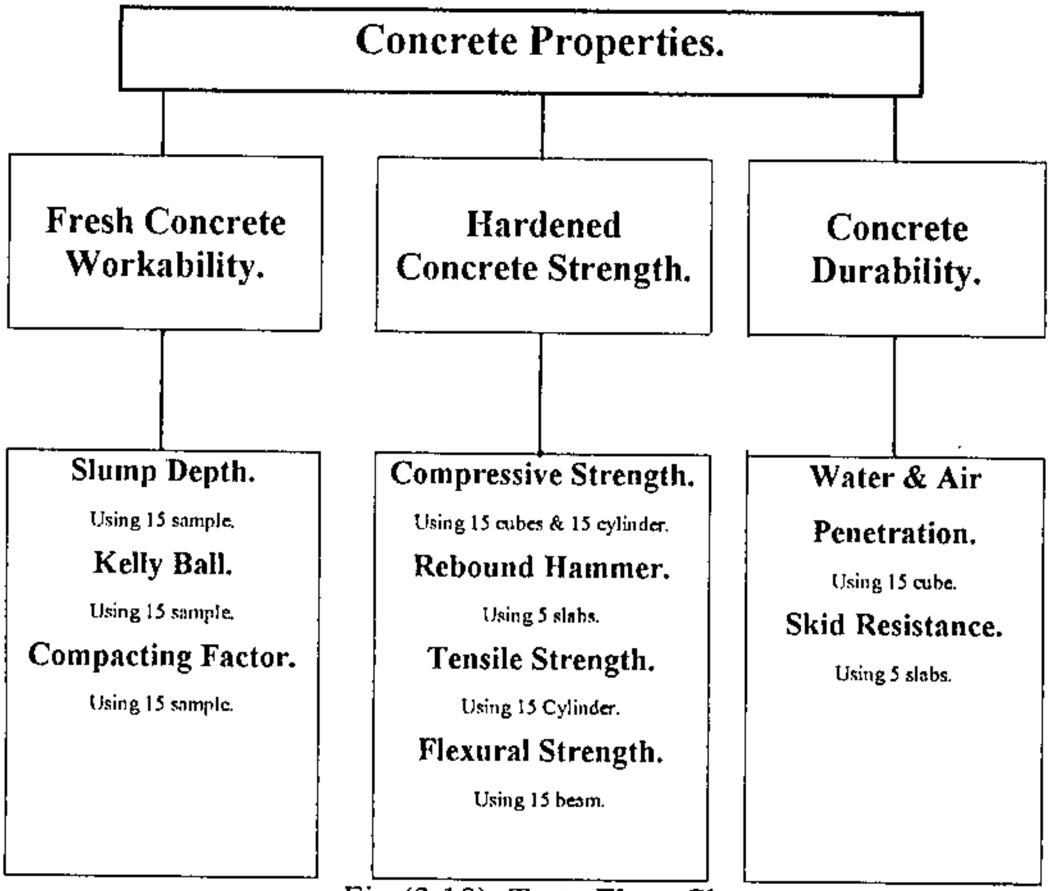


Fig (3.10). Tests Flow-Chart.

3.4.2 Fresh Concrete Workability.

Workability is a term, which is easily understood, but is relatively hard to define. Perhaps the easiest way to do so is to say that the more workable a mix, the less works required to compact it fully.

Neville (1995) indicated that the workable concrete is the concrete that can be mixed, transported, placed and finished sufficiently easily and without segregation.

Workability definition has been developed by the British Road Research Lab (B.R.R.L.) as the amount of useful internal work necessary to produce a full compaction. (Glanville, 1947).

Also, concrete workability affected by many variables, these include: water-cement ratio, cement-aggregate ratio, aggregates shape, size and gradation.

Unfortunately, at this time there is no single test which is universally accepted as a truly measuring workability, but several tests like slumping, kelly ball and compacting factor have been developed to determine the consistency of the fresh concrete.

3.4.2.1 The Slump Test.

It is the workability test, which is most widely used through the world today.

In this test the newly mixed concrete is placed in a specified manner in the frustum of acone having a bottom diameter of (203 mm), a top diameter of (105 mm) and a height of (305 mm).

When the container has been filled with concrete and leveled at top, the mould is carefully removed by raising vertically and the freed concrete is allowed to subside. The difference between the height of the mould and final height of the concrete called the slump depth.

Slump test applied on a fifteen sample that has a different five percentage of steel swarf, according to the British Standard (BS: 188). Test results are shown in table (3.8).

3.4.2.2 Kelly Ball Test.

It is a simple field test covered by (ASTM-C-360) and rarely used in Britain. It consists of the determination of the depth to which a (152 mm) diameter metal hemisphere weighing (13.6 kg) will sink under its own weight into fresh concrete. Sketch of the apparatus known as Kelly ball is shown in figure (3.11).

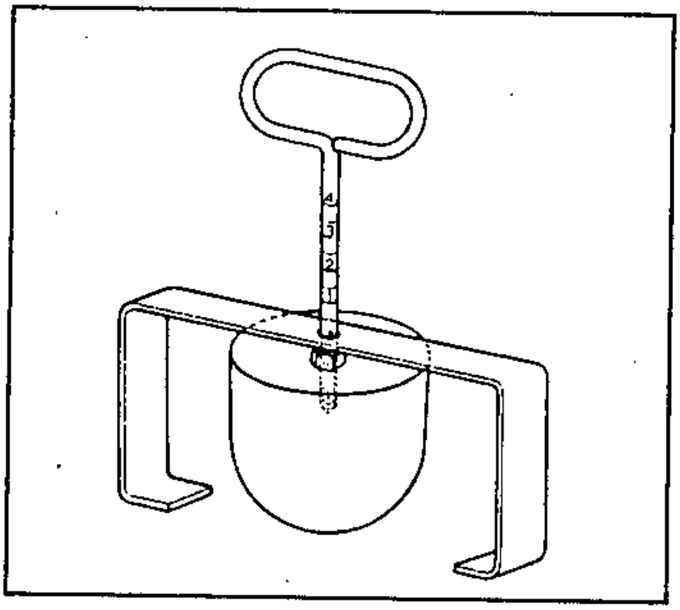


Fig (3.11). Kelly Ball. (Neville, 1995).

Kelly ball test applied on a fifteen sample that has a different five percentage of steel swarf. Test results are shown in table (3.9).

Table (3.8). Slump Test Results.

Swarf Percentage (%)	Specimen No.	Slump Depth (mm)	Average Slump Depth (mm)	Slump Type
0.00	1- 2- 3-	40 50 45	45	True
0.85	1- 2- 3-	90 70 80	80	True
1.7	1- 2- 3-	65 70 75	70	True
2.55	1- 2- 3-	60 65 55	60	True
3.4	1- 2- 3-	25 25 30	26.50	True

Table (3.9). Kelly Ball Test Results.

Swarf Percentage (%)	Specimen No.	Kelly Ball Penetration (mm)	Average Kelly Ball Penetration (mm)
0.00	1- 2- 3-	26 25 30	27
0.85	1- 2- 3-	41 46 49	45
1.7	1- 2- 3-	43 42 38	41
2.55	1- 2- 3-	33 31 41	35
3.4	1- 2- 3-	22 20 18	20

3.4.2.3 Compacting Factor Test.

There is no generally accepted method of directly measuring workability, i.e. the amount of work necessary to achieve full compaction.

Probably the best test yet available uses the inverse approach: the degree of compaction achieved by a standard amount of work is determined.

The degree of compaction, called compacting factor, is measured by the density ratio, i.e. the ratio of the density actually achieved in the test to the density of the same concrete fully compacted.

The compacting factor test, which apparatus shown in figure (3.12), was developed at the British Road Research Lab, and is described by the British Standard (BS: 1881). (Neville, 1995).

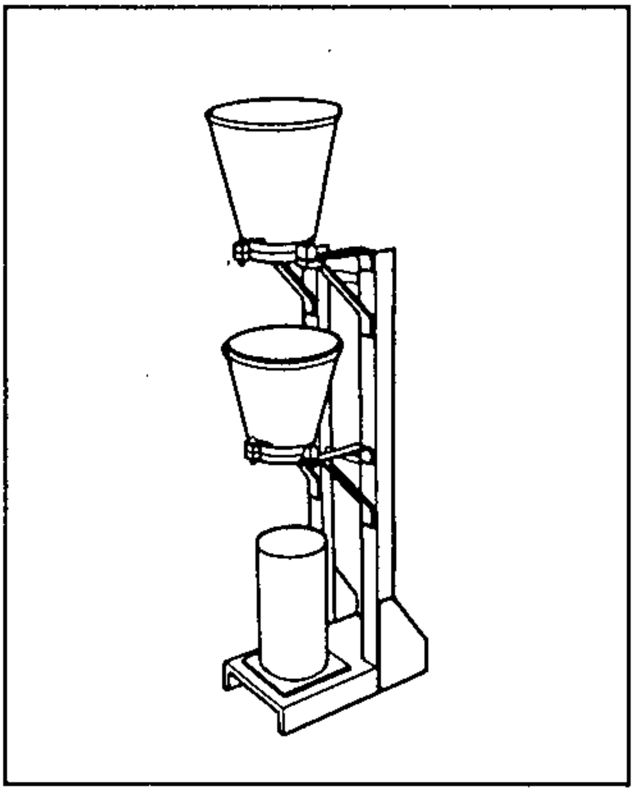


Fig (3.12). Compacting Factor Apparatus. (Neville, 1995).

Compacting factor test applied on fifteen different samples. Test results are shown in table (3.10).

Table (3.10). Compacting Factor Test Results

Swarf Percentage (%)	Specimen No.	Compacting Factor	Average Compacting Factor
0.00	1-	0.855	0.853
	2-	0.843	
	3-	0.862	
0.85	1-	0.917	0.912
	2-	0.897	
	3-	0.922	
1.7	1-	0.89	0.887
	2-	0.865	
	3-	0.906	
2.55	1-	0.852	0.843
	2-	0.837	
	3-	0.841	
3.4	1-	0.813	0.793
	2-	0.789	
	3-	0.777	

3.4.3 Hardened Concrete Strength.

The strength of the hardened concrete is the property, which is of primary importance in the construction of rigid pavement, because strength is directly related to the structure of the hardened concrete paste.

For a given cement and acceptable aggregates, the strength that may be developed by workable, properly placed mixture of cement, aggregate, and water (under the same mixing, curing, and testing conditions) is influenced by the:

- Ratio of cement to mixing water.
- Ratio of cement to aggregate.
- Grading, surface texture, shape, and strength of aggregate particles.
- Maximum size of the aggregate. (Neville, 1995).

3.4.3.1 Compressive Strength

The most common of all tests on hardened concrete is the compressive strength test, partly because it is an easy test to make, and partly because many of the desirable characteristics of concrete are qualitatively related to its strength; but mainly because of the intrinsic importance in construction. (Neville, 1995).

The compressive strength of concrete depend mainly on the water/cement ratio, cement/aggregate ratio, cement type, the aggregates properties, curing adequacy, and concrete itself age.

The following types of specimens were tested by the compressive test using the universal testing machine that has a (15 kn/second) loading rate:

- Cube specimens of (15x15x15) cm dimension were prepared and tested according to the British Standards (BS: 1881) at 28 day age, with a total number of a fifteen sample that has different five percentage of steel swarf. Table (3.11) indicates the test condition and results.
- Cylinder specimens of (15x30) cm were tested according to (ASTM-C-39) at 28-day age, with a total number of a fifteen sample that has different five percentage of steel swarf. This test assisted in modulus of elasticity study.

The unit compressive strength was calculated by dividing the maximum load achieved by the cross-section area. Table (3.12) indicates the test conditions and results.

Table (3.11). Compression Test Results For Cube Specimens.

Swarf Percentage (%)	Specimen No.	Specimen Density (Kg/m³)	Average Density (Kg/m³)	Specimen Compressive Strength (Kg/cm²)	Average Strength (kg/cm²)
0.00	1- 2- 3-	2293.6 2296.6 2302.5	2297.6	329.0 283.5 353.5	322
0.85	1- 2- 3-	2305.18 2296.3 2300.0	2300.5	302.7 316.0 298.0	305.6
1.7	1- 2- 3-	2260.7 2302.0 2300.0	2286.5	326.5 288.7 291.0	302.1
2.55	1- 2- 3-	2296.29 2302.0 2302.5	2300	293.18 244.8 258.4	265.43
3.4	1- 2- 3-	2256.0 2263.0 2300.5	2273	260.44 262.5 256.4	259.8

Table (3.12). Compression Test Results of Cylinder Specimens.

Swarf Percentage (%)	Specimen No.	Specimen Density (kg/m^3)	Average Density (kg/m^3)	Specimen Compressive Strength (kg/cm^2)	Average Strength (kg/cm^2)	Cylindrical to cubic Compressive Strength Ratio
0.00	1- 2- 3-	2245 2248 2239	2244	253 315 296	288	0.894
0.85	1- 2- 3-	2258 2245 2262	2255	281.82 272.18 275.56	276.52	0.905
1.7	1- 2- 3-	2253 2238 2259	2250	264.71 265.81 292.85	274.45	0.908
2.55	1- 2- 3-	2234.3 2243.9 2229.4	2236	198.8 217.2 268.7	228.25	0.860
3.4	1- 2- 3-	2209 2223 2213	2215	223.3 211.25 219.77	218	0.839

3.4.3.2 The Modulus 'of Elasticity.

Like many other structural materials, concrete has a certain degree of elasticity.

Modulus of elasticity defined as the rate of stress changing with respect to the elastic strain. Figure (3.13) shows the different type of concrete elastic modulus.

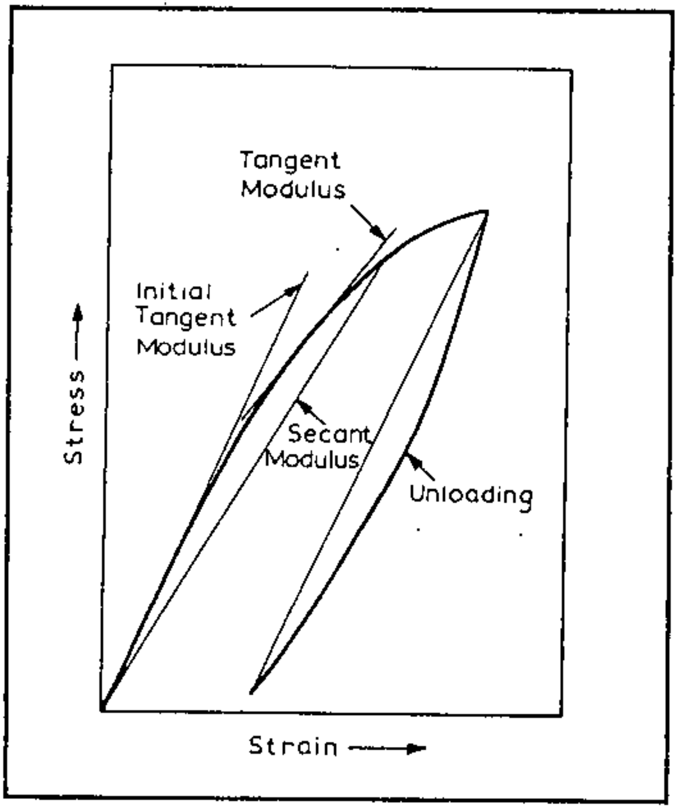


Fig (3.13). Typical Stress Strain Curve for Concrete.

(Neville, 1995).

Modulus of elasticity of concrete is a function of its compressive strength unit weight, age and type of curing.

The following empirical formula for approximate calculation of elastic modulus was given by (ACI, 1990).

$$E_c = W_c^{1.5}\, 0.043\, f_c^{0.5} \text{ ....(3-1)}$$

where;

E_c = concrete modulus of elasticity (N/mm^2).

W_c = concrete density (kg/m^3).

fc = average compressive strength of cylinder 15x30 cm (N/mm2).

Table (3.13) shows the results of modulus of elasticity calculated depending on the cylinder specimens compressive results indicated in table (3.12).

Table (3.13). Modulus of Elasticity Results.

Swarf Percentage (%)	Specimen No.	Specimen Density (kg/m^3)	Specimen Compressive Strength (kg/cm^2)	Calculated Modulus of Elasticity (kg/cm^2)	Average Calculated Modulus of Elasticity (Kg/cm^2)
0.00	1-	2245	253	$2.324\text{x}10^5$	$2.475\text{x}10^5$
	2-	2248	315	$2.598\text{x}10^5$	
	3-	2239	296	$2.50\text{x}10^5$	
0.85	1-	2258	281.8	$2.47\text{x}10^5$	$2.44\text{x}10^5$
	2-	2245	272.18	$2.409\text{x}10^5$	
	3-	2262	275.56	$2.45\text{x}10^5$	
1.7	1-	2253	264.71	$2.388\text{x}10^5$	$2.43\text{x}10^5$
	2-	2238	265.81	$2.37\text{x}10^5$	
	3-	2259	292.85	$2.52\text{x}10^5$	
2.55	1-	2234.3	198.8	$2.044\text{x}10^5$	$2.18\text{x}10^5$
	2-	2243.9	217.2	$2.15\text{x}10^5$	
	3-	2229.4	268.7	$2.37\text{x}10^5$	
3.4	1-	2209	223.3	$2.13\text{x}10^5$	$2.11\text{x}10^5$
	2-	2223	211.25	$2.09\text{x}10^5$	
	3-	2213	219.77	$2.12\text{x}10^5$	

3.4.3.3 Rebound Hammer Test.

Various attempts to devise non-destructive tests have been made, but few have been highly successful. One method has found particle application within a limited scope is the rebound hammer test, which also known as the impact hammer test.

The test is based on the principle that the rebound of an elastic mass depends on the hardness of surface against which the mass impinges.

In the rebound hammer test as pring-loaded mass has a fixed amount to energy imparted to it by extending a spring to a fixed position, this is achieved by pressing the plunger against the surface of the concrete under test upon release, the mass rebound from the plunger, still in contact with the concrete surface, and the distance traveled by the mass expressed as a percentage of the initial extension of the spring, is called the rebound number; its indicated by a rider moving along a graduated scale.

The test is sensitive to local variation in the concrete; for instance, the presence of a large piece of aggregate immediately underneath the plunger would result a high rebound number; conversely, the presence of avoid in a similar position would lead to a very low result.

The plunger must be always normal to the surface of the concrete under test, but the position of the hammer relative to the vertical will affect the rebound number. This is due to gravity action on the travel of the mass in the hammer.

Changes affecting only the surface of the concrete, such on the degree of saturation at the surface or carbonation would be misleading as far as the properties of concrete within the structure are concerned. Method of calibration and guidance for use of the hammer is covered by the British Standards (BS: 4408). (Neville, 1995).

Rebound hammer test was applied on the five slabs containing different swarf contents. Ten trails were applied on each slab. Test results are shown in table (3.14).

Table (3.14). Rebound Hammer Test Results.

Swarf Percentage (%)	Hammer Reading										Average Rebound No.
	Trial Number										
	1	2	3	4	5	6	7	8	9	10	
0.00	34	32	31	33	34	33	33	31	34	35	33
0.85	32	32	33	31	33	32	33	31	33	30	32
1.7	32	31	31	30	30	31	32	30	31	32	31
2.55	33	27	29	32	30	28	31	30	28	32	30
3.4	28	29	26	28	29	28	29	30	27	26	28

3.4.3.4 Flexural Strength.

The determination of flexural strength is essential to estimate the load at which the concrete member may crack.

The absence of cracking is of considerable importance in maintaining the continuity of concrete structure and in many cases in prevention of corrosion of reinforcement, beside that the flexural test is essential to the design of roads slabs, and air field runways.

Also, because it is difficult to determine the tensile strength of concrete, it is computed by the flexural testing. Thus the flexural tensile strength of failure on the modulus of rapture is determined and used when necessary.

The value of the modulus of rapture depends on the dimensions of the beam, and above all, on the arrangement of loading, one point load, or tow-point loading.

Flexural strength can be calculated using the following formula:

$$MR = 1.5PL/(bd^2)\ldots\ldots\ldots(3.2).$$ (Neville, 1995).

Where:

MR = modulus of rapture (N/mm^2)

p = breaking load (N).

L = span between supporting roller (mm).

b = beam width (mm).

d = beam depth (mm).

This test was carried out according to the British Standards (BS: 1881) on fifteen beam specimens that has different five percentage of steel swarf. Flexural test results are shown in table (3.15).

Table (3.15). Modulus of Rupture Test Results.

Swarf Percentage (%)	Specimen No.	Specimen Flexural Strength (kg/cm^2)	Average Strength (kg/cm^2)
0.00	1-	45.7	46.13
	2-	56.3	
	3-	36.4	
0.85	1-	57.25	57.48
	2-	56.85	
	3-	58.35	
1.7	1-	32.15	42.37
	2-	40.8	
	3-	54.16	
2.55	1-	31.34	29.38
	2-	26.75	
	3-	30.05	
3.4	1-	28.18	27.12
	2-	26.66	
	3-	26.53	

3.4.3.5 Tensile Strength.

The direct methods to determine the tensile strength suffer from a number of difficulties related to holding the specimen properly in the testing machine without introducing stress concentration and to the application of uniaxial tensile load which is free from eccentricity to the specimen. Even a very small eccentricity of load will include bending and axial force condition and the concrete fails at apparent tensile stresses other than the tensile strength.

Because of the difficulties involved in conducting the direct tension test, a number of indirect methods have been developed to determine the tensile strength.

In these tests, in general, a compressive force is applied to a concrete specimen in such a way that the specimen fails due to tensile stresses caused in the specimen. The tensile stress at which failure occurs, is the tensile strength of concrete.

The splitting tests are well known as indirect tests used for determining the tensile strength of concrete, sometimes referred to as the splitting tensile strength of concrete.

The test consists of applying compressive line loads along the opposite generator of concrete cylinder placed with its axis horizontal between the plates as shown in figure (3.14). Due to the applied line loading a fairly uniform tensile stress is induced.

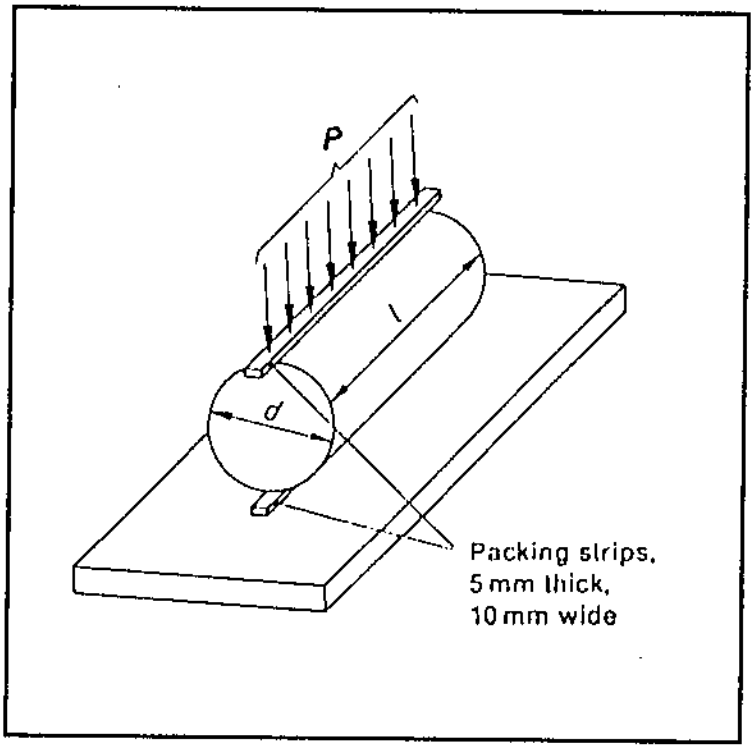


Fig (3.14). Arrangement of Loading of Cylindrical specimens for Determining the Tensile Splitting Strength.

(DIN- 1048, 1990).

The magnitude of this tensile stress is given by the following equation:

$$T = 14P/(22DL)$$ ....(3-3). (Neville, 1995).

Where:

T = modulus of rupture (N/mm^2).

P = applied load (N).

D = cylinder specimen diameter (mm).

L = cylinder specimen height (mm).

For determining the tensile strength, splitting test has the following benefits:

- The test is simple to perform and gives more uniform results than other tension tests.
- The strength determined is closer to actual tensile strength than is the modulus of rapture value.

- The same mould can be used for casting specimens for both compression and tension test. (Awdat, 1991).

Splitting test was applied on fifteen concrete cylinders that have five different percentage of steel swarf at the age of 28 day, according to the British Standards (BS: 1881).

Splitting test results are shown in table (3.16) with their different content of swarf.

Table (3.16). Splitting Test Results.

Swarf Percentage (%)	Specimen No.	Specimen Splitting Strength (kg/cm^2)	Average Strength (kg/cm^2)
0.00	1- 2- 3-	39 36.36 30.3	35.22
0.85	1- 2- 3-	39.27 43.27 39.6	40.7
1.7	1- 2- 3-	32.4 27.47 37.78	32.25
2.55	1- 2- 3-	21.73 26.73 26.26	24.9
3.4	1- 2- 3-	22.77 22.68 24.16	23.18

3.4.4 Concrete Durability.

Durability is the ability of concrete to withstand the effects of the service conditions to which it exposed.

In some cases the word "durability" refers to the ability of materials to resist actions such as weathering, chemical attack, corrosion, erosion, fire, abrasion, and freezing. (Husien, 1993).

The absence of durability may be caused either by environment to which the concrete is exposed or by internal causes within the concrete itself. The external causes can be physical, chemical, or mechanical: they may be due weathering, occurrence, of extreme temperatures, abrasion, and the attack by natural or industrial liquids and gases. The internal causes are the alkali-aggregate reaction, volume changes due to the differences in thermal properties of aggregate and cement paste, and above all the **permeability** of concrete.

Deterioration of concrete is rarely due to one isolate cause: concrete can often is satisfactory despite some undesirable features, but with an additional adverse factor damage will occur. For this reason, it is some times difficult to assign trouble to particular factor, but the quality of concrete, in the broad sense of the word, though with a special reference to permeability. (Neville, 1995).

3.4.4.1 Water Penetration of Concrete

Penetration of concrete by materials in solution may adversely affect its durability. This penetration depends on the permeability of concrete. Since permeability determines the relative ease with which concrete can become saturated with water; permeability has an important bearing on the vulnerability of concrete to frost. Furthermore, in the case of reinforce concrete, the ingress of moisture and of air will result in the corrosion of steel. Since this leads to an increase in the volume of the steel cracking and spalling of the concrete cover maywell follow.

Both the cement paste and the aggregate contain pores. In addition the concrete as a whole contains voids caused by incomplete compaction or by bleeding. These voids may occupy between fraction of one percent and ten percent of the volume of concrete. Since aggregate particles are enveloped by the cement paste, in fully compacted concrete it is the permeability of the paste that has the greatest effect on the permeability of the concrete.

The permeability of cement paste varies with the progress of hydration. In a fresh paste the flow of water is controlled by the size, shape, and concentration of original cement paste grains. With the progress of the hydration the permeability decreases rapidly, (see figure 3.15).

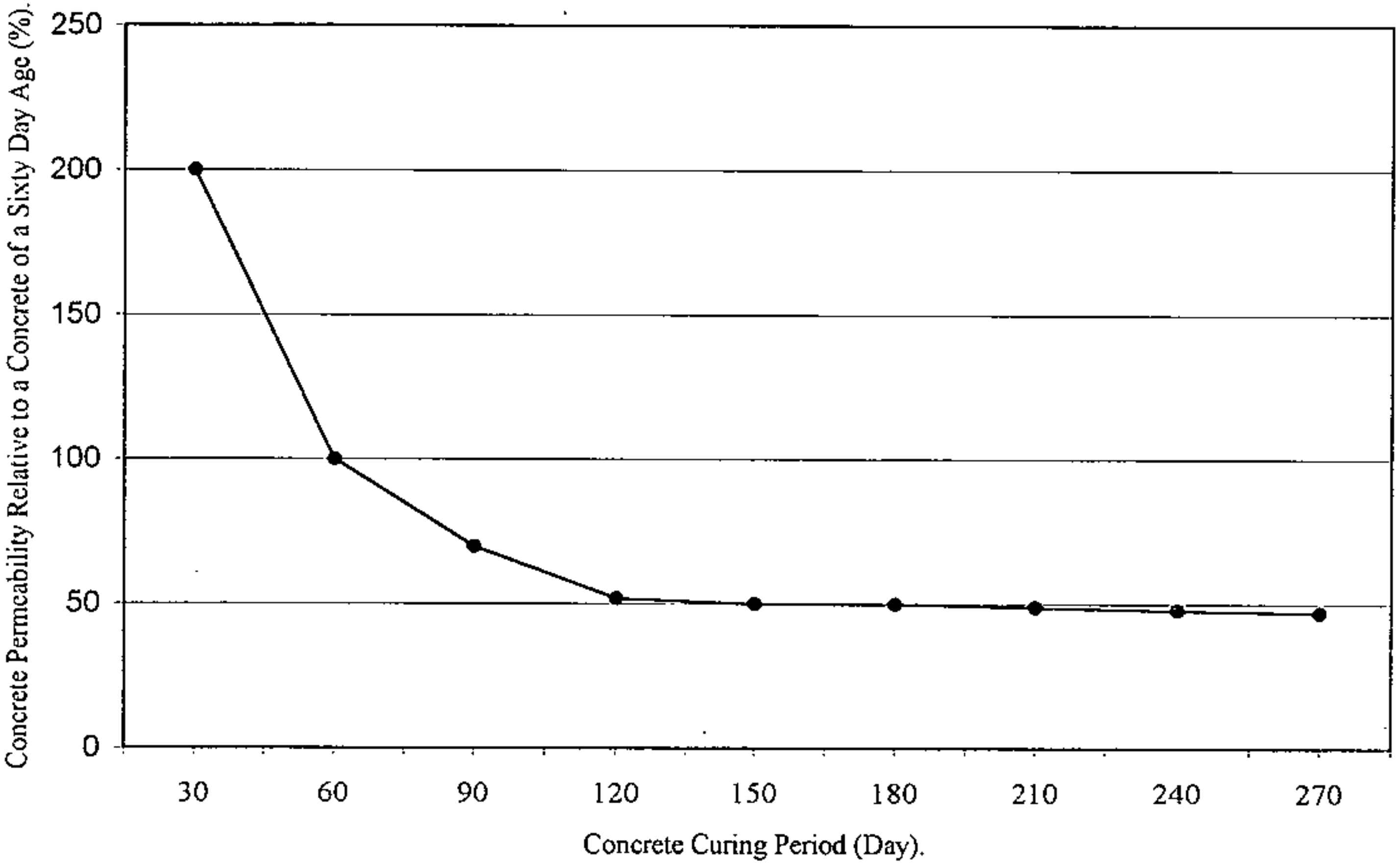


Fig (3.15). Reduction on Permeability of Cement Paste with Respects to the Progress of Hydration.
(Abu Deyya, 1986).

For the pastes that hydrate to the same degree, the permeability is lower the higher the cement content of the paste, i.e. the lower the water/cement ratio, (see figure 3.16).

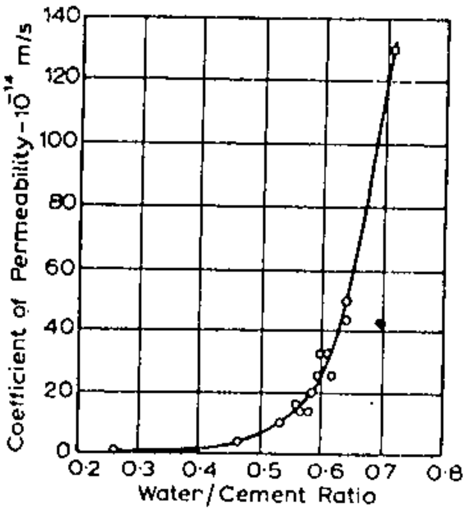


Fig (3.16). Relation Between Permeability and Water-cement Ratio for Mature Cement Pastes. (Neville, 1995).

The permeability of concrete is affected also by the properties of cement. For the same water/cement ratio, coarse cement tends to produce a paste with a higher prosity than finer cement. The compound composition of the cement affects permeability as it influences the rate of hydration.

Finally the permeability of the aggregate itself affects the behavior of the concrete, if the aggregate has a very low permeability its presence will reduce the concrete permeability.

The penetration of concrete can be measured in the laboratory by means of simple tests that covered by (DIN: 1048). The test gives a measure of the water penetration in meters during a given period of time in seconds.

Table (3.17) shows the results of water penetration tests, which were applied on specimens of different five percentage of swarf.

3.4.4.2 Air Penetration

Permeability of concrete to air is of interest primarily in structures such as sewage tanks and gas purifiers, the usual requirement being that the concrete should be air tight under a specified internal pressure. More recently, interests in air permeability of concrete arose in connection with pressure results in nuclear reactor. (Neville, 1995).

As in the case of water penetration, the rate of flow of air depends on the thickness of the concrete and on the pressure applied.

Increasing the cement content of the mix has been found to decrease the air permeability, but the true factor is the water/cement ratio. It is also through a reduction in the actual water/cement ratio that air entrainment reduces the air permeability. The addition of fly ash or pozzolana has beneficial effects. (Keer, 1989).

Grading of aggregate seems to be particularly important in reducing air penetration of concrete.

Using the water penetration and depending on the fluid mechanics principles under the steady state of flow conditions, air penetration can be estimated by the following equation, which presented by (Vennard and Street, 1982):

$$V_a = (D_w \times V_w) / D_a \,\ldots\ldots\ldots\, (3.4)$$

where:

V_a = air velocity through a specified section, (m/s).

V_w = water velocity through a specified section, (m/s).

D_a = air density at the ideal conditions (1.225 kg/m^3).

D_w = water density at the ideal conditions (998.2 kg/m^3).

The air penetration where estimated by using the last equation, for each one of the previous water penetration coefficients, results are explained in table (3.17).

Table (3.17). Concrete Penetration Test Results.

Swarf Percentage (%)	Specimen No.	Specimen Water Penetration (mm)	Average Water Penetration (mm)	Specimen Air Penetration (10^3mm)	Average Air Penetration (10^3mm)
0.00	1-	12.0	13.6	9.78	11.13
	2-	14.0		11.41	
	3-	15.0		12.22	
0.85	1-	17.0	16.7	13.85	13.57
	2-	22.0		17.9	
	3-	11.0		8.96	
1.70	1-	28.8	23.65	23.47	19.29
	2-	24.3		19.8	
	3-	17.9		14.59	
2.55	1-	26.5	21.15	21.6	17.25
	2-	22.0		17.93	
	3-	15.0		12.22	
3.40	1-	41.0	29.31	33.41	23.9
	2-	31.0		25.26	
	3-	16.0		13.04	

3.4.4.3 Skid Resistance.

3.4.4.3.1 Introduction

Pavement surface is subjected to a various stresses and influences caused by heavy loads under traffic and due to physical and chemical action of environmental conditions.

Abrasion, which is defined as the wearing a way of a surface by rubbing or friction process brought about by traffic, is a major one of these influences.

Resistance to abrasion is great importance when the traffic consists largely of metal wheeled-trucks carrying heavy loads, as in warehouses.

The abrasion resistance of concrete pavement is a function of the following variables, (Neville, 1995):

- Resistance to abrasion was found to be proportional to the concrete compressive strength.
- Resistance to abrasion was found to be proportional to the water/cement ratio.
- Different aggregates have varying levels of wearing according to there ability to withstand the influences that may causes changes in surface texture, where the microscopic wearing action could be uniform polishing, or differential wearing which improve friction at low and high speed, while macroscopic wearing action is detrimental to skid resistance at high speed; therefore, to withstand wearing and resist abrasion, aggregate must be very hard, not easily crushed or fractured under traffic loading stresses, and can resist chemical effects and environmental condition. (Leavon and Sako, 1990).

- Grading of aggregate has also some influence, an over-sanded mix leading to a greater loss in abrasion, if the material of the mix are the same. Special tests may be necessary if metallic or other hardener is used in the surface layer of concrete.

Haddadin (1993) also denoted that the results of tests made at Pennsylvania State University, of wear and polishing showed fairly high correlation exists between percentage weight loss due to wear and the rate of friction for some types of materials.

3.4.4.3.2 Measuring of Skid Resistance.

Portable tester, shown in figure (3.17) was developed at the British Road Research Lab to provide highway engineers with a routine and reasonable of checking the resistance of road surfaces to skidding.

Test consists of a dynamic pendulum impact-type tester used to measure the energy lost when a rubber slider edge is propelled over a test surface. It measures surface frictional characteristics due to micro texture but not due to macro texture. The values measured are referred to as British Pendulum (tester) Numbers (BPN) for flat surfaces. The test is covered by (ASTM-E-303).

The British Pendulum skid tester, was used to test the skid resistance for concrete slabs that were casted with five different percentage of steel swarf, and the test results are shown in table (3.18).

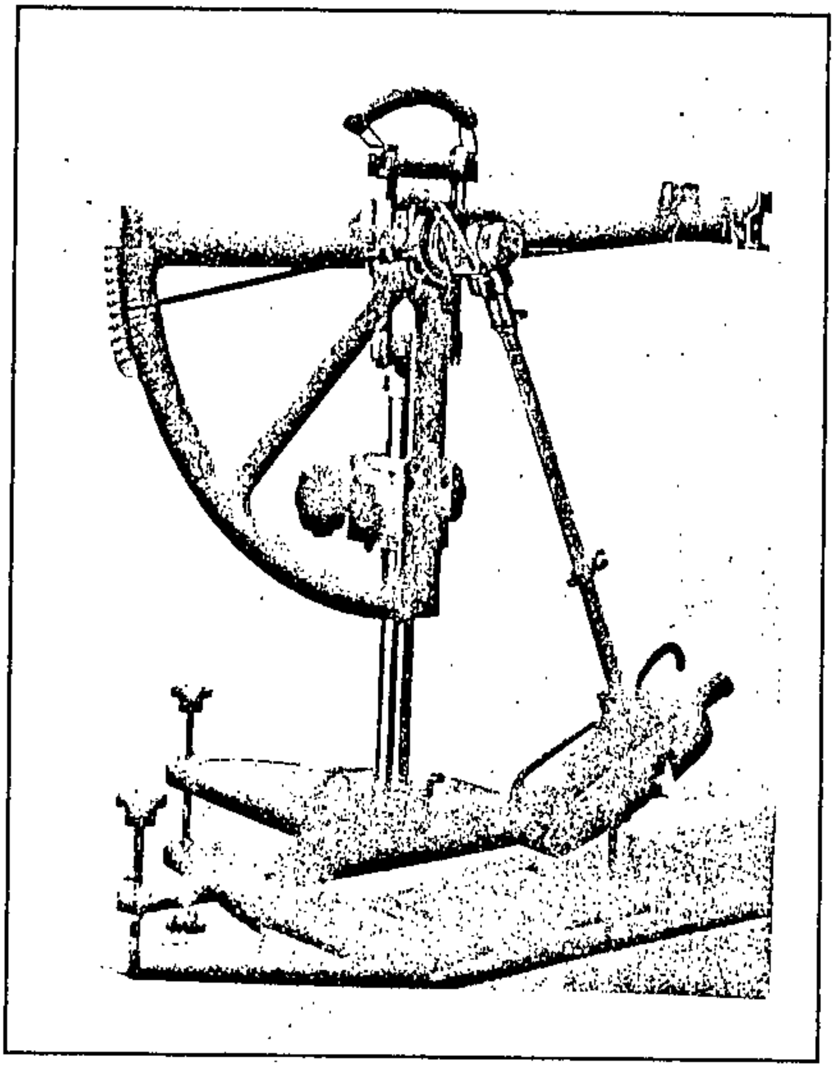


Fig (3.17). Apparatus Used to Measure the Coefficient of Friction of the Surface. (Sharif, 1988).

Table (3.18). Skid Resistance Test Results.

Swarf Percentage (%)	Specimen No.	Specimen British Pendulum No. (BPN).	Average British Pendulum No. (BPN).
0.00	1- 2- 3- 4-	86 85 87 83	85.25
0.85	1- 2- 3- 4-	72 68 70 71	70.25
1.70	1- 2- 3- 4-	61 60 57 58	59.0
2.55	1- 2- 3- 4-	54 52 55 56	54.25
3.4	1- 2- 3- 4-	40 43 41 44	42.0

CHAPTER FOUR

ANALYSIS OF DATA

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ANALYSIS OF DATA

4.1 Introduction.

The use of waste materials with concrete in order to improve its properties is rather a new concept in construction, that is expected to grow with research and with greater understanding of its behavior under the different type of stresses.

One of the objectives of this study focused on studying the advantages for using steel (iron) swarf with concrete pavements construction, if any, and its effects on the concrete behavior, so that it may be encouraging to be used.

Fresh, hardened and durable concrete tests were applied to examine its behavior and properties before and after using steel swarf. The obtained results that are summarized in table (4.1), were encouraging, and it is expected that significant benefits can be achieved by using of steel swarf with concrete.

In the following sections, the previous data were analyzed and discussed to check the goodness of the last expectations and assumptions.

Table (4.1). Summary of the Tests Results.

- x = test results average.
- s = test results standard deviation.

Test Type		Swarf Percentage %				
		0.0	0.85	1.7	2.55	3.4
Slump (mm)	x	45	80	70	60	26.67
	s	5	10	5	5	2.88
Kelly Ball (mm)	x	27	45.33	41	35	20
	s	2.65	4.04	2.65	5.29	2.0
Compacting Factor	x	0.853	0.912	0.887	0.843	0.793
	s	0.0996	0.013	0.0206	0.00776	0.018
Compressive Strength (kg/cm^2)	x	322	305	302.1	265.46	259.65
	s	35.79	9.33	21.19	24.95	3.32
Concrete Density (kg/m^3)	x	2244	2255	2250	2235.86	2215
	s	4.58	8.9	10.81	7.37	7.211
Elasticity Modulus (10^4 kg/cm^2)	x	24.74	24.4	24.4	21.88	21.05
	s	1.39	0.31	1.06	1.66	0.2121
Rebound No.	x	33	32	31	30	28
	s	1.35	1.054	0.816	2	1.33
Flexural Strength (kg/cm^2)	x	46.13	57.48	42.37	29.38	27.12
	s	9.95	0.77	11.09	2.367	0.917
Splitting Strength (kg/cm^2)	x	35.22	40.71	32.55	24.9	23.2
	s	4.46	2.22	5.15	2.76	0.829
Water Penetration (mm)	x	13.6	16.7	23.65	21.15	29.31
	s	1.53	5.5	5.48	5.8	12.58
Air Penetration (10^3mm)	x	11.13	13.57	19.29	17.25	23.9
	s	1.24	4.47	4.46	4.72	10.25
BPN	x	85.25	70.25	59.0	54.25	42.0
	s	1.708	1.707	1.826	1.708	1.826

4.2 Fresh Concrete Results Analysis.

4.2.1 Slump Test.

The results of the slump test, which were shown in table (3.8), were graphically presented in figure (4.1).

The analysis of variance and the hypothesis testing of mean for the slump test results were also carried out and are shown in tables (4.2 and 4.3).

It could be noted from the figure that the slump depth of the swarf mixes is increasing as swarf content is increased up to a certain value after which slump started to decrease, which means that it has an optimum swarf content (0.85%) for maximum slump.

Analysis of variance and analysis of mean tables, indicate the followings:

- Analysis of variance as is shown in table (4.2), which covers a comparison among the five different percentages of the swarf that were used in concrete, indicates with a confidence level of (99.0%) that the swarf percentage in the mix significally affects the concrete slump. This is reflected in its F-value (F_0=36.14) being much higher than the critical $F_{0.01,4,10}$ = 5.99.
- Analysis of mean as is shown in table (4.3) indicates with a probability of (87.8%) that the no swarf mixes have a slump depth less than the upper limits of the mix design (50mm). Also it insures with a probability of (98.9%) that the no swarf mixes have a slump depth higher than the lower limits of the mix design (25mm).

- Analysis of mean table indicates also the followings:

1) At a confidence level of (99.7%) the slump of the 0.85-percent swarf concrete increases by (77.8%) compared to the no swarf concrete.
2) At a confidence level of (99.8%) the slump depth of the 1.70-percent swarf concrete increases by (55.5%) compared to the no swarf concrete.
3) At a confidence level of (98.86%) the slump depth of the 2.55-percent swarf concrete increases by (33.3%) compared to the no swarf concrete.
4) At a confidence level of (99.7%) the slump depth of the 3.40-percent swarf concrete decreases by (38.1%) compared to the no swarf concrete. But at the same time it indicates at a confidence level of (77.6%) that the slump depth of 3.40-percent swarf concrete was higher than the lower limit of the mix (25mm).

Table (4.2). Analysis of Variance for the Slump Depth Test.

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	F_0
Swarf Addition	5306.33	4	1326.58	36.14
Error	367.0	10	36.7	
Total	5673.33	14		

Table (4.3). Analysis of Mean for the Slump Depth Test Results.

Swarf Percentage (%)	0.85	1.7	2.55	3.4	No Swarf	
					Upper Limit=50 (mm)	Lower Limit=25 (mm)
Difference of Mean	t_0 *= -5.4	t_0 = -6.1	t_0 = -3.66	t_0 = 5.4	t_1**=-1.73	t_1=6.9

* t_0 = mean slump with no swarf – mean slump with swarf.

** t_1 = mean slump with swarf – slump limits of the design.

Regression statistical analysis is also performed. The analysis indicates that the slump test results align with the following polynomial regression with a correlation factor of ($R^2 = 0.963$):

$$Y_1 = 49.15 + 39.2X - 13.73X^2 \text{ .... } (4.1)$$

where:

Y_1 = slump depth (mm).

X = swarf percentage (%).

The previous regression is represented graphically in figure (4.1).

Using the differentiation principles, a maximum slump depth of (77.10mm), at an optimum steel swarf content of (1.42%) can be achieved under the given mix design conditions, and the used materials properties, that is:

$$dY_1/dX = 39.2 - 27.46X = 0.0$$

$$X = 1.42\%$$

$$Y_1 (X = 1.42\%) = 77.10 \text{ mm.}$$

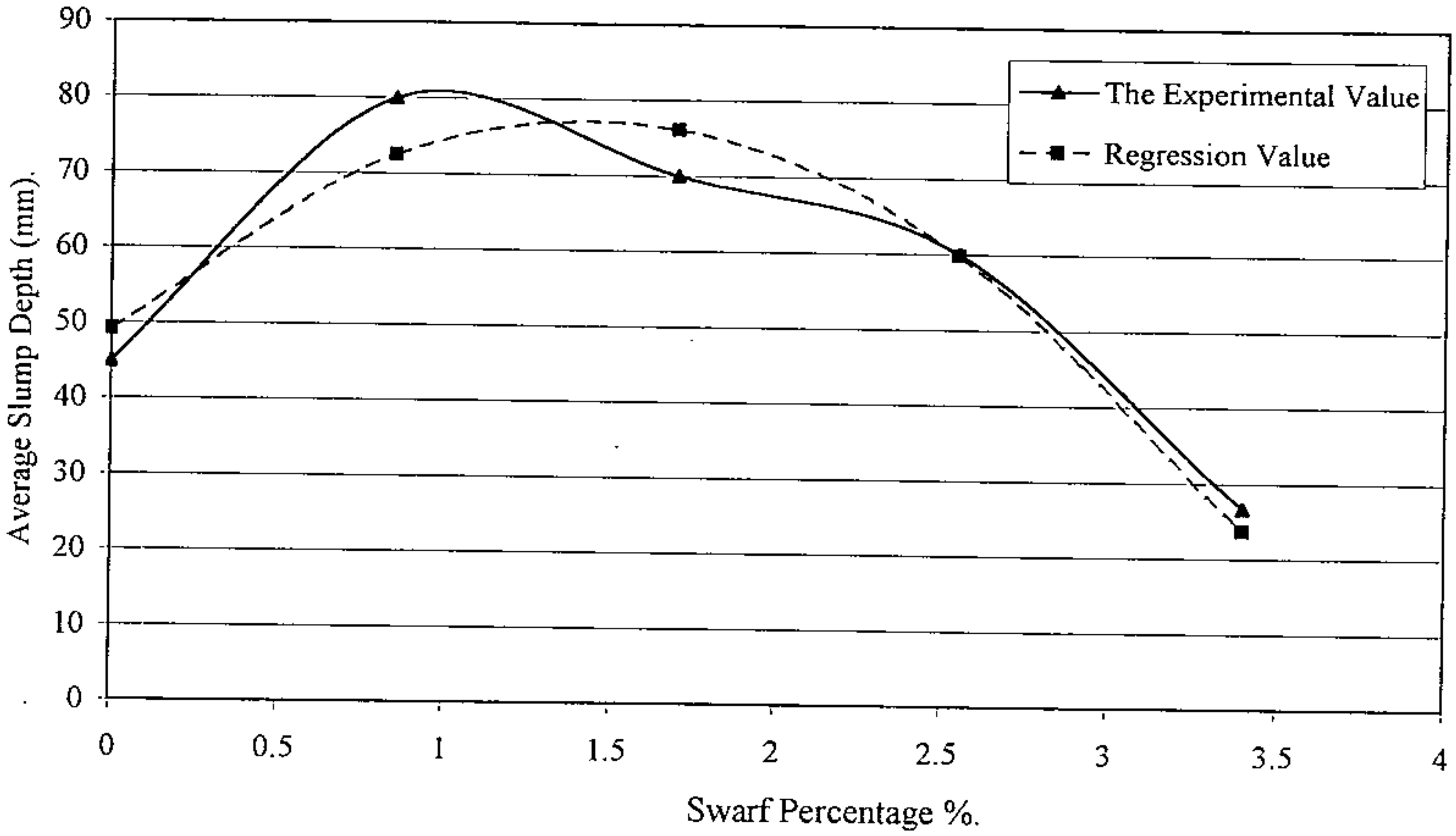


Fig (4.1). Relationship between Average Slump Depth and Swarf Percentage.

4.2.2 Kelly Ball Test.

The results of the kelly ball test, that were shown in table (3.9) were graphically presented in figure (4.2).

The analysis of variance, and the hypothesis testing of mean for the kelly ball penetration results were also carried out and are shown in tables (4.4 and 4.5).

It could be noted from the figure that the average ball penetration of the swarf mixes is increasing as swarf content is increased up to a certain value after which the ball penetration started to decrease, which means that there is an optimum swarf content (0.85%) for maximum ball penetration.

Analysis of variance as is shown in table (4.4), which covers a comparison among the five different percentages of swarf indicates with a confidence level of (99%) that the swarf percentage in the mixes significally affects the average kelly ball penetration in the concrete. This is reflected in its F-value (F_0=25.45) being much higher than the critical $F_{0.01,4,10}$ = 5.99.

Analysis of mean as is shown in table (4.5) indicates the followings:

1) At a confidence level of (99.8%) the ball penetration of the 0.85-percent swarf concrete increases by (67.9%) compared to the no swarf concrete.
2) At a confidence level of (99.8%) the ball penetration of the 1.7-percent swarf concrete increases by (51.8%) compared to the no swarf concrete.

3) At a confidence level of (95.6%) the ball penetration of the 2.55-percent swarf concrete increases by (29.6%) compared to the no swarf concrete.
4) At a confidence level of (98.77%) the ball penetration of the 3.4-percent swarf concrete decreases by (25.9%) compared to the no swarf concrete.

Regression statistical analysis is also performed. The analysis indicates that the kelly ball penetration has the following polynomial regression with a correlation factor of (R^2 = 0.492):

$$Y_2 = 29.43 + 19.25x - 6.87X^2 \text{ .... } (4.2)$$

where:

Y_2 = kelly ball penetration (mm).

X = swarf percentage (%).

The previous regression is represented graphically in figure (4.2).

Using the differentiation principles, a maximum penetration of (42.90 mm) at a steel swarf percentage of (1.4%) can be achieved under the given mix design conditions, and the used material properties, that is:

$$dY_2/dX = 19.25 - 13.74X = 0.0$$

$$X = 1.4\%$$

$$Y_2\,(X=1.4\%) = 42.9 \text{ mm.}$$

Table (4.4). Analysis of Variance for the Kelly Ball Penetration Test.

Source of Variation	Sum of Squares	Degree of Freedom	Mean Squares	F_0
Swarf Addition	1269.33	4	317.32	25.45
Error	124.67	10	12.467	
Total	1394	14		

Table (4.5). Analysis of Mean for the Kelly Ball Penetration Test Results.

Swarf Percentage %	0.85	1.7	2.55	3.4
Difference of Mean*	$t_0 = -6.54$	$t_0 = -6.45$	$t_0 = -2.3$	$t_0 = 3.6$

* Difference of Mean = mean kelly ball penetration with no swarf – mean kelly ball penetration with swarf.

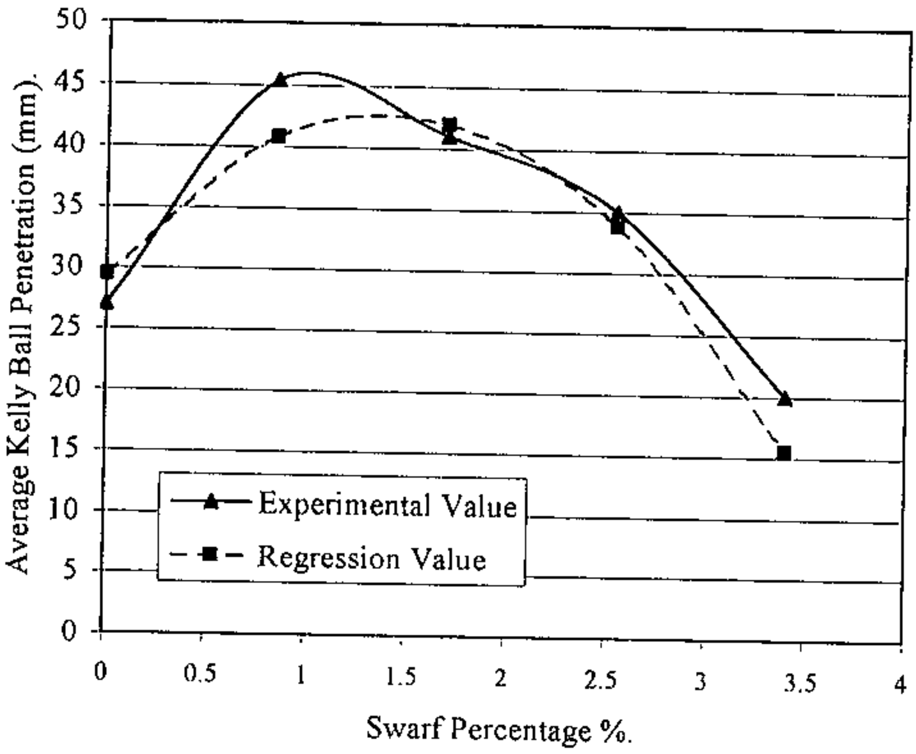


Fig (4.2). Relationship between Average Kelly Ball Penetration and Swarf Percentage.

4.2.3 Compacting Factor Test.

The results of the compacting factor tests that were shown in table (3.10) were graphically presented in figure (4.3). The analysis of variance and the hypothesis testing of mean were applied on the test results and are shown in table (4.6 and 4.7) respectively.

It could be observed from the graph that the compacting factor test results emphasize the results of the previous fresh concrete tests.

Also it could be noted from the graph that the compacting factor of the swarf mixes is increasing as swarf content is increased up to a certain value after which it started to decrease, which means that there is an optimum swarf content (0.85%) for maximum compacting factor.

Analysis of variance as is shown in table (4.6), which covers a comparison among the five different percentages of swarf indicates at a confidence level of (99%) that the swarf percentage in the concrete mixes significally affects the average compacting factor of the concrete. This is reflected in its F-value (F_0=30.05) being much higher $F_{0.01,4,10}$ = 5.99.

Table (4.6). Analysis of Variance for the Compacting Factor Test.

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	F_0
Swarf Addition	0.0244	4	$6.1\text{x}10^{-3}$	30.05
Error	$2.03\text{x}10^{-3}$	10	$2.03\text{x}10^{-4}$	
Total	0.264	14		

Analysis of mean as is shown in table (4.7) indicates the followings:

1) At a confidence level of (99.7%) the compacting factor of the 0.85-percent swarf concrete increases by (6.9%) compared to the no swarf concrete.
2) At a (96.15%) level of confidence the compacting factor of the 1.7-percent swarf concrete increases by (4.0%) compared to the no swarf concrete.
3) At a (79.9%) level of confidence the compacting factor of the 2.55-percent swarf concrete decreases by (1.2%) compared to the no swarf concrete.
4) At a confidence level of (98.77%) the compacting factor of the 3.4-percent swarf concrete decreases by (7.0%) compared to the no swarf concrete.

Table (4.7). Analysis of Mean for the Compacting Factor Test Results.

Swarf Percentage %	0.85	1.7	2.55	3.4
Difference of Mean*	$t_0 = -5.42$	$t_0 = -2.43$	$t_0 = 0.999$	$t_0 = 3.6$

* Difference of Mean = mean compacting factor with no swarf – mean compacting factor with swarf.

The following polynomial regression can be constructed depending on the previous test results with a correlation factor of ($R^2 = 0.373$):

$$Y_{3.1} = 0.883 + 0.03x - 0.25X^2 \text{ .... } (4.3)$$

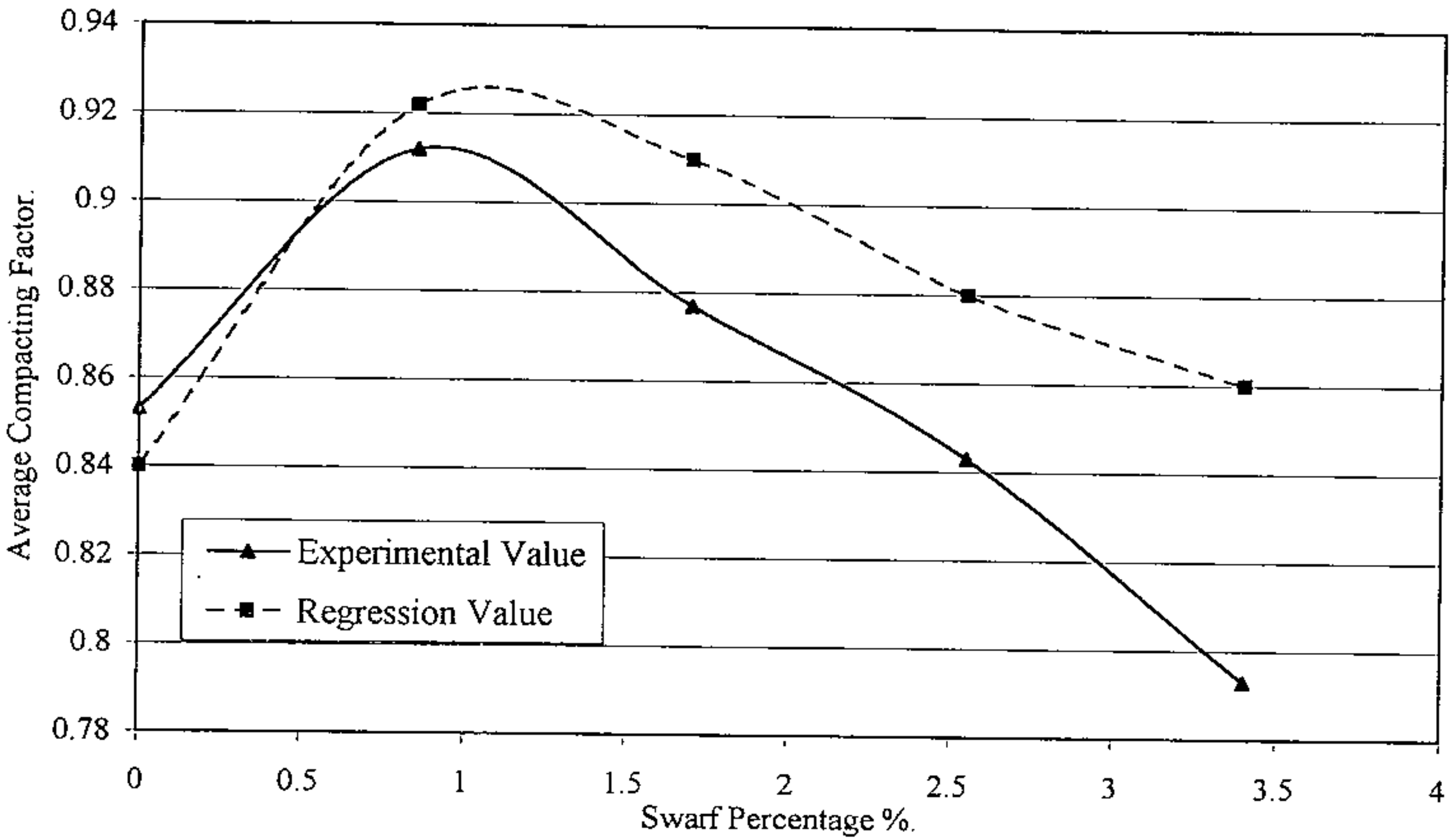
Another regression for the compacting factor results can be modified to achieve a correlation factor of ($R^2 = 0.68$). This regression represented in figure (4.3) and aligns with the following formula:

$$Y_{3.2} = 0.84 - 0.0533X + 0.135X^{1/3} \text{ .... } (4.4)$$

where:

$Y_{3.1}$ & $Y_{3.2}$ = compacting factor.

X = swarf percentage (%).



Fig(4.3). Relationship between Average Compacting Factor and Swarf Percentage.

4.3 Hardened Concrete Results Analysis.

4.3.1 Compression Test.

The results of the compressive strength, which were shown in tables (3.11 and 3.12), were graphically presented in figures (4.4 and 4.5) respectively. The analysis of variance and the hypothesis testing of mean for the test results were applied and are shown in tables (4.8 and 4.9) respectively.

It could be noted from the graphs that the compressive strength of the swarf mixes is somewhat lower than the no swarf mixes. Also, it could be observed that an increase in swarf content causes a decrease in compressive strength. A more detailed discussion of this phenomenon will be presented in the following sections.

Analysis of variance as is shown in table (4.8), which covers a comparison among the five different percentages of swarf, indicates with a confidence level of (95%) that the swarf percentage in the mix simply affects the average compressive strength of concrete. This is reflected in its F-value (F_0=4.47) being simply higher than the critical value $F_{.05,4,10}$ = 3.48.

Table (4.8). Analysis of Variance for the Compressive Strength.

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	F_0
Swarf Addition	8706.1	4	2176.25	4.47
Error	4867.446	10	486.74	
Total	13573.54	14		

Table (3.12) also indicate that the ratios of the cylindrical compressive strength to the cubic compressive strength have a range of (0.839-0.908).

The analysis of mean as shown in table (4.9) indicates also the following points:

1) At a confidence level of (93%) the compressive strength of no swarf concrete is higher than the required strength of the design (270 kg/cm^2).
2) At a confidence level of (75.05%) the compressive strength of the 0.85-percent swarf concrete decreases by (5.1%) compared to the no swarf concrete. But at the same time it indicates with a confidence level of (98.8%) that the 0.85-percent swarf concrete has a compressive strength higher than the required compressive strength of the design (270 kg/cm^2).
3) At a confidence level of (76.6%) the compressive strength of the 1.7-percent swarf concrete decreases by (6.2%) compared to the no swarf concrete. But at the same time it indicates with a confidence level of (93.4%) that the 1.7-percent swarf concrete has a compressive strength higher than the required compressive strength of the design (270 kg/cm^2).
4) At a confidence level of (95.4%) the compressive strength of the 2.55-percent swarf concrete decreases by (17.6%) compared to the no swarf concrete. At the same time it indicates at a confidence level of (60.9%) that the 2.55-percent swarf concrete has a compressive strength lower than the required compressive strength of the design (270 kg/cm^2).
5) At a confidence level of (97.8%) the compressive strength of the 3.4-percent swarf concrete decreases by (19.3%) compared to the no swarf concrete. At the

same time it indicates at a confidence level of (99.7%) that the 3.4-percent swarf concrete has a compressive strength lower than the required compressive strength of the design.

Table (4.9). Analysis of Mean for the Compressive Strength Test Results.

Concrete Condition	Swarf Percentage %				
	0.0	0.85	1.7	2.55	3.4
Difference of Mean (t_0)*	$t_0 = 2.516$	$t_0 = 6.6$	$t_0 = 2.6$	$t_0 = 2.24$	$t_0 = 3.0$
Difference of Mean (t_1)**	-	$t_1 = 0.768$	$t_1 = .826$	$t_1 = -.32$	$t_1 = -5.4$

* t_0 = mean compressive strength with no swarf – mean compressive strength with swarf.

** t_1 = mean compressive strength with swarf – compressive strength of the design.

Regression statistical analysis is also performed. The analysis indicates that the standard compressive strength has the following linear regression with a correlation of (R^2 = 92.53%):

$$Y_{5.1} = 323.69 - 19.32X \text{ ………. } (4.5)$$

where:

$Y_{5.1}$ = the average standard compressive strength (kg/cm^2).

X = swarf percentage (%).

The cylindrical compressive strength aligns with the following linear regression with a correlation factor of (R^2 = 88.83%):

$$Y_{5.2} = 294.81 - 22.28X \text{ ………. } (4.6)$$

where:

$Y_{5.2}$ = the average cylindrical compressive strength (kg/cm^2).

X = swarf percentage (%).

Both of the regressions were shown graphically in figures (4.4 and 4.5) respectively.

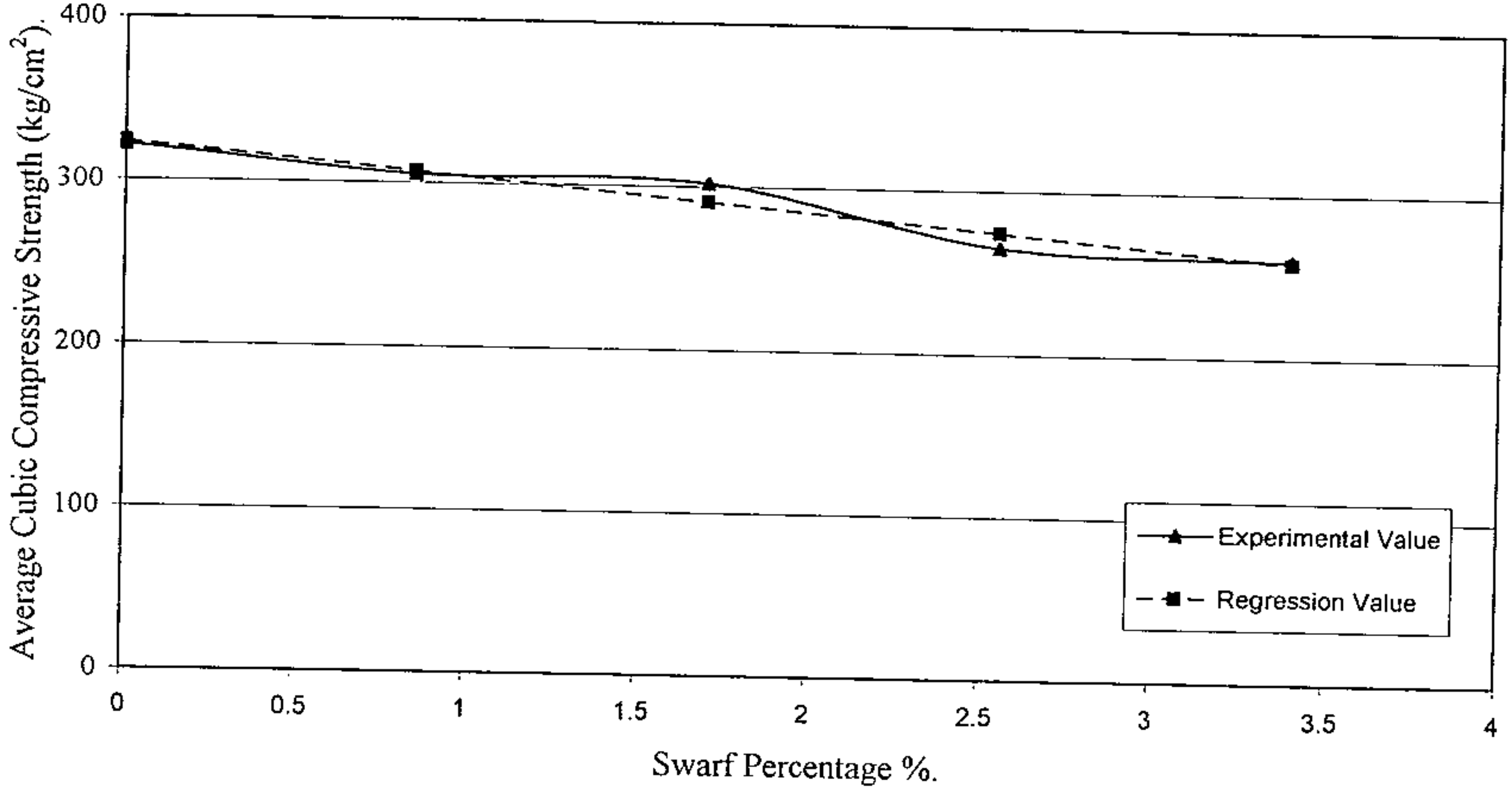


Fig (4.4). Relationship between Average Cubic Compressive Strength and Swarf Percentage.

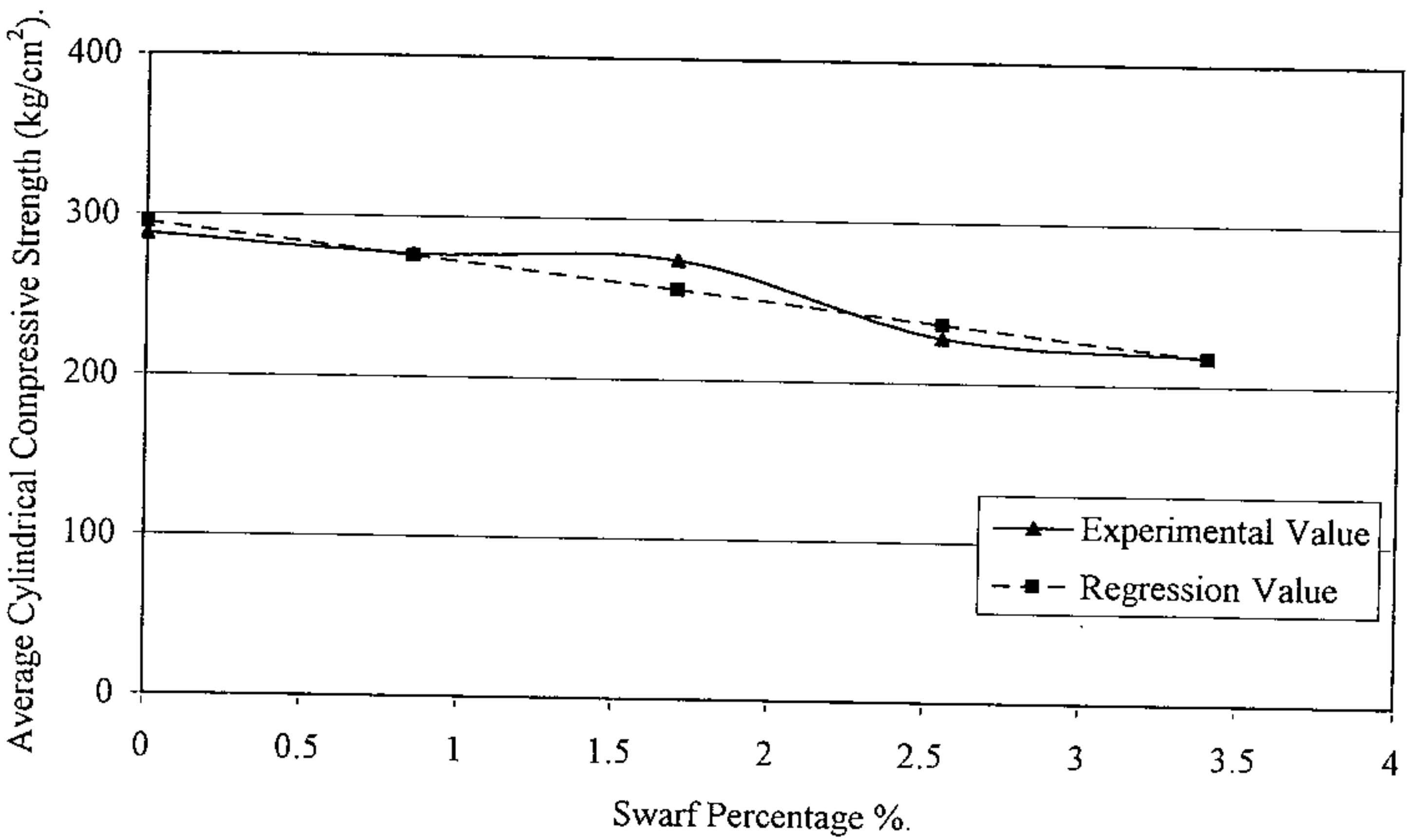


Fig (4.5). Relationship between Average Cylindrical Compressive Strength and Swarf Percentage.

4.3.2 Concrete Density.

The results of the density that were shown in tables (3.11 and 3.12), were graphically presented in figure (4.6) from which it can be noted that the density of the swarf mixes are somewhat higher than no swarf mixes. Also, it could be observed that an increase in swarf content is a compainedly by an increase in the density up to a limit beyond, which there is a reduction start to take a place. A more detailed discussion of this phenomenon will be presented in the following sections.

Table (4.10) shows the analysis of variance that covers a comparison among the five different percentages of swarf and indicates at a confidence level of (99%) that the swarf percentage in the mix significally affects the average density of concrete. This is reflected in its F-value (F_0=11.4) being higher than the critical value $F_{0.01,4,10}$ = 5.99.

Table (4.10). Analysis of Variance for Concrete Density.

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	F_0
Swarf Addition	2949.27	4	737.31	11.4
Error	646.79	10	64.6	
Total	3596.06	14		

Hypothesis testing of mean for concrete density results, which are summarized in table (4.11), indicates the following points:

1) At a confidence level of (92.9%) the density of the 0.85-percent swarf concrete increases by (0.5%) compared to the no swarf concrete.

2) At a confidence level of (77.37%) the density of the 1.7-percent swarf concrete increases just by (0.26%) compared to the no swarf concrete.
3) At a confidence level of (90.7%) the density of the 2.55-percent swarf concrete decreases by (0.36%) compared to the no swarf concrete.
4) At a confidence level of (99.77) the density of the 3.4-percent swarf concrete decreases by (1.3%) compared to the no swarf concrete.

Table (4.11). Analysis of Mean for the Concrete Density Test Results.

Swarf Percentage %	0.85	1.7	2.55	3.4
Difference of Mean*	$t_0 = -1.89$	$t_0 = -0.883$	$t_0 = 1.62$	$t_0 = 5.86$

* Difference of Mean = mean density with no swarf – mean density with swarf.

Depending on the previous results the following polynomial regression can be constructed with a correlation factor of (0.478):

$$Y_{6.1} = 2302.82 - 62.4X - 9.52X^2 \quad \text{..........} \quad (4.7)$$

But the following linear regression with a correlation factor of (R^2 = 0.605), that represented graphically in figure (4.6) can also aligns with the previous test results:

$$Y_{6.2} = 2255.4 - 9.075X \quad \text{.........} \quad (4.8)$$

where:

$Y_{6.1}$ & $Y_{6.2}$ = concrete density (kg/m^3).

X = swarf percentage (%).

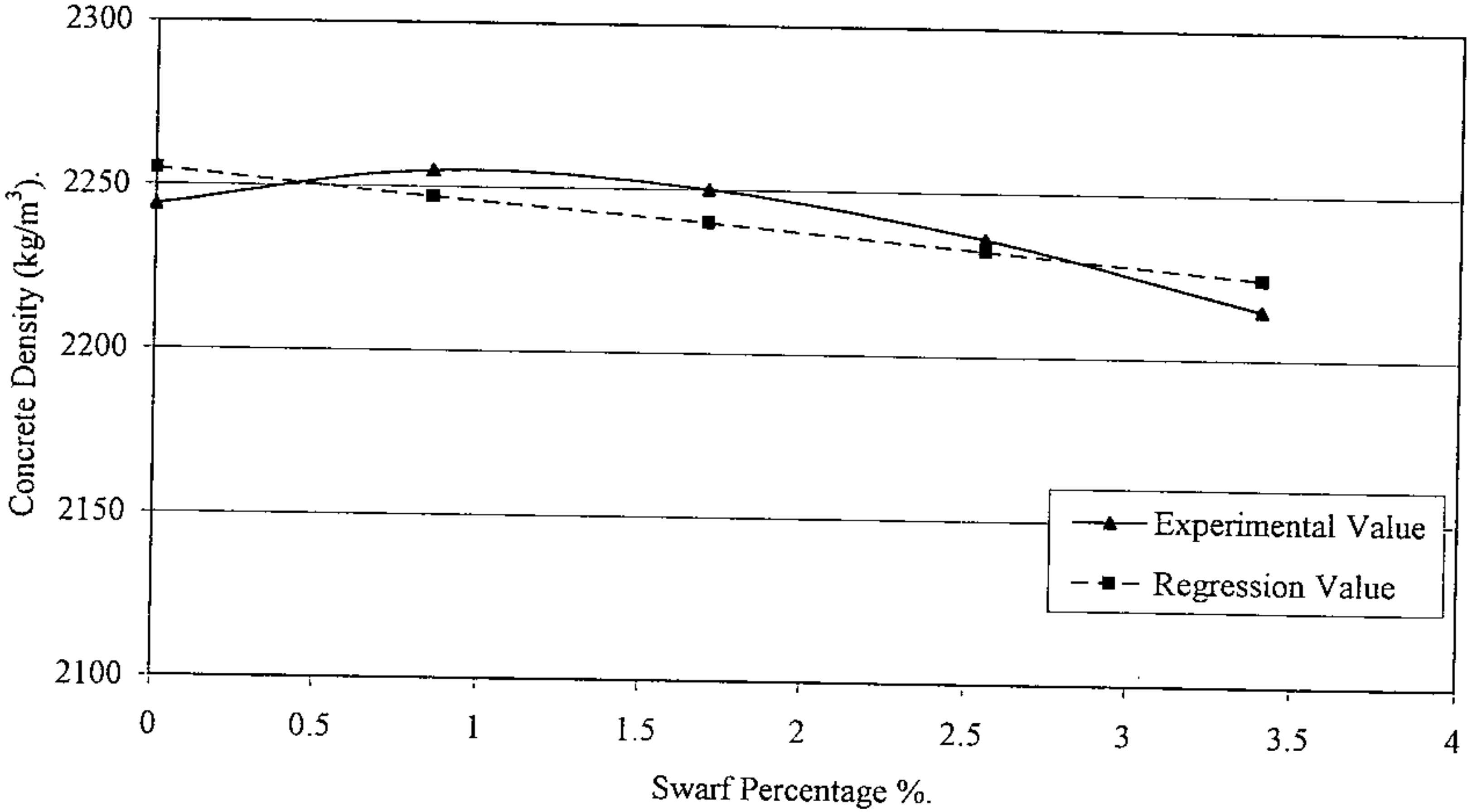


Fig (4.6). Relationship between Concrete Density and Swarf Percentage.

4.3.3 Modulus of Elasticity.

The results of elasticity modulus, which were shown in table (3.13), were graphically represented in figure (4.7).

It could be noted from the figure that the elasticity modulus of the swarf concrete is somewhat lower than the no swarf one. Also, it could be observed that an increase in the swarf content causes a decrease in the modulus of elasticity. This result is expected, that why, modulus of elasticity is a function of the compressive strength and concrete density at the same time. A more detalied discussion of this phenomenon will be presented in the following sections.

Table (4.12) shows the result of the analysis of variance for the elasticity modulus, which covers a comparison among the five different contents of swarf, and indicates with a confidence level of (99%) that the swarf percentage simply affects the modulus of elasticity of concrete. This is reflected in its F-value (F_0=7.6) being simply higher than the critical value $F_{0.1,4,10}$ = 5.99.

Table (4.12). Analysis of Variance for the Modulus Elasticity.

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	F_0
Swarf Addition	$3.34x10^9$	4	$8.3x10^8$	7.6
Error	$1.1x10^9$	10	$1.1x10^8$	
Total	$4.44x10^9$	14		

The hypothesis testing of mean also applied on the results, it was summarized in table (4.13) and indicates the following points:

1) At a confidence level of (69%) the elasticity modulus of the 0.85-percent swarf concrete decreases by (1.37%) compared to the no swarf concrete.
2) At a confidence level of (61.8%) the elasticity modulus of the 1.7-percent swarf concrete also decreases by (1.37%) compared to the no swarf concrete.
3) At a confidence level of (95.57%) elasticity modulus of the 2.55-percent swarf concrete decreases by (11.56%) compared to the no swarf concrete.
4) At a confidence level of (99.43%) the elasticity modulus of the 3.4-percent swarf concrete decreases by (14.9%) compared to the no swarf concrete.

Table (4.13). Analysis of Mean for the Elasticity Modulus Results.

Swarf Percentage %	0.85	1.7	2.55	3.4
Difference of Mean*	$t_0 = 0.555$	$t_0 = 0.333$	$t_0 = 2.28$	$t_0 = 4.5$

* Difference of Mean = mean elasticity modulus with no swarf – mean elasticity modulus with swarf.

The following linear regression which was shown in figure (4.7) was constructed with a correlation factor of (R^2 = 0.847) to combine the elasticity modulus and the swarf contents.

$$Y_7 = 2.527\text{x}10^5 - 1.1647\text{x}10^5 X \quad \text{.........} \; (4.9)$$

where:

Y_7 = concrete elasticity modulus (kg/cm^2).

X = swarf percentage (%).

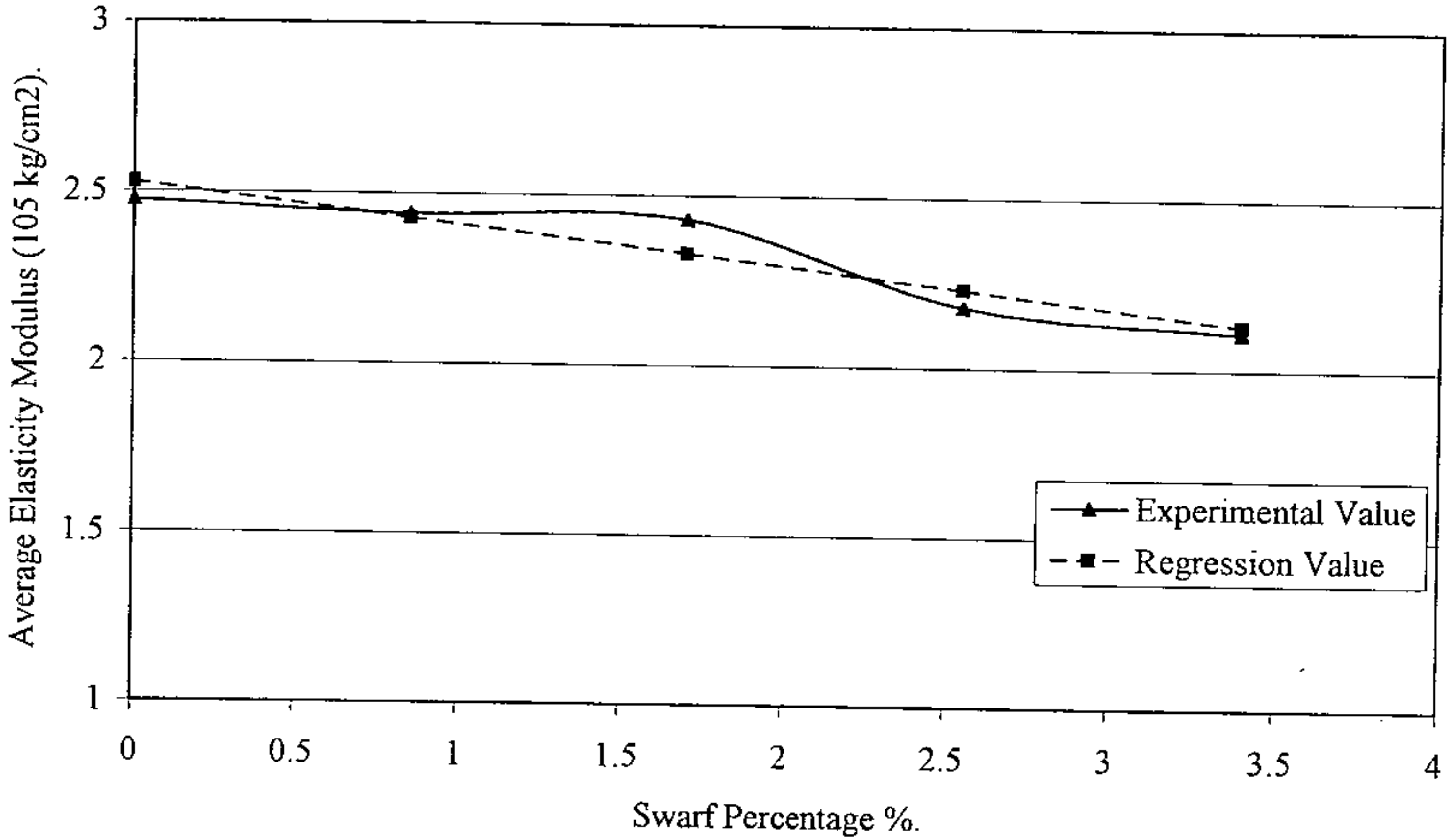


Fig (4.7). Relationship between Modulus of Elasticity and Swarf Percentage.

4.3.4 Rebound Hammer Test.

Results of the rebound hammer test that were shown in table (3.14), were graphically presented in figure (4.8).

It could be noted from the graph that the rebound number of the swarf concrete is simply lower than the no swarf mixes.

It could also be observed that an increase in the swarf content causes somewhat a reduction in the rebound number. This result is expected specially that the rebound number is a function of the compressive strength, the density and the elasticity modulus of concrete. A more detailed discussion of this phenomenon will be presented in the following sections.

Table (4.14) shows the analysis of variance result for the rebound number that was indicates at a confidence level of (99%) that the swarf content in concrete significally affects on the rebound number value. This is reflected in its F-value (F_0=19.9) being higher than the critical $F_{0.01,4,45}$ = 3.79.

Table (4.14). Analysis of Variance for the Rebound Hammer Test.

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	F_0
Swarf Addition	148	4	37	19.9
Error	84	45	1.86	
Total	232	49		

The hypothesis testing of mean for rebound number test results was summarized in table (4.15) and indicates the following points:

1) At a confidence level of (79.25%) the rebound number of the 0.85-percent swarf concrete decreases by (3%) compared to the no swarf concrete.
2) At a confidence level of (99.9%) the rebound number of the 1.7-percent swarf concrete, 2.55-percent swarf concrete and 3.4-percent swarf concrete decreases by (6.06, 9.09 and 15.1)% respectively, compared to the no swarf concrete.

Table (4.15). Analysis of Mean for the Rebound Hammer Test Results.

Swarf Percentage %	.85	1.7	2.55	3.4
Difference of Mean*	$t_0 = 0.87$	$t_0 = 3.89$	$t_0 = 3.9$	$t_0 = 8.53$

* Difference of Mean = mean rebound number with no swarf – mean rebound number with swarf.

The following linear regression which represented in figure (4.8) can be constructed with a correlation factor of (R^2 = 0.973) depending on the previous test results.

$$Y_8 = 33.2 - 1.412X \quad \text{..........} \quad (4.10)$$

where:

Y_8 = rebound number.

X = swarf percentage (%).

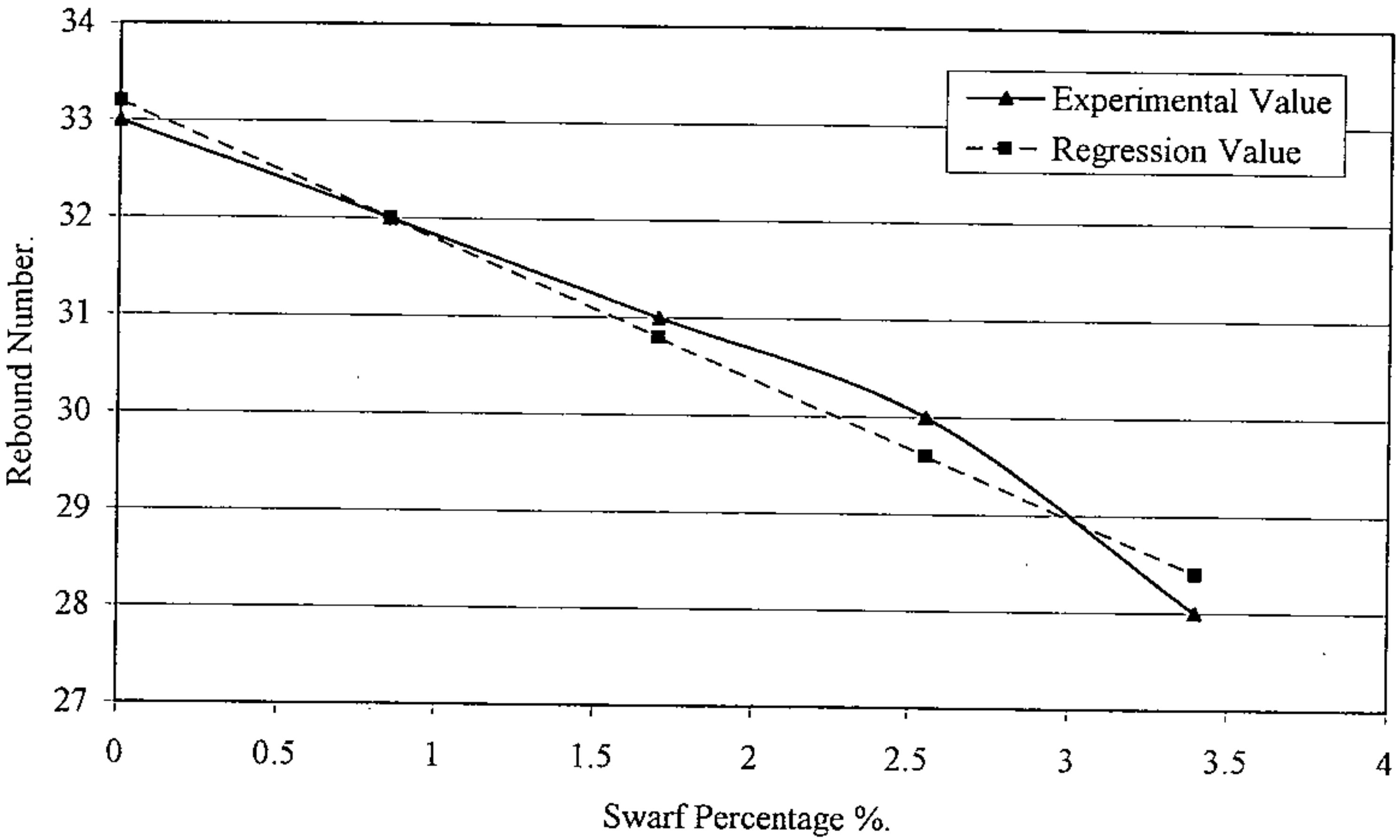


Fig (4.8). Relationship between Rebound Number and Swarf Percentage.

4.3.5 Flexural Strength Test.

Results of the flexural strength test, which were shown in table (3.15), were graphically represented in figure (4.9).

It could be noted from the graph that the flexural strength of the swarf concrete is higher than its value of the no swarf one at some contents of swarf. At the same time the flexural strength of the no swarf concrete is somewhat higher than its value of the swarf concrete at some other swarf contents. It could also be observed that as the swarf content increased the flexural strength also increased up to a maximum limit then it decreased. A more detailed discussion of this phenomenon will be presented in the following sections.

Table (4.16) shows the analysis of variance for the flexural strength result, which indicates at a confidence level of (99%) by a comparison among the five different contents of the swarf that using of swarf is significally affects the average flexural strength of concrete. This is reflected in its F-value (F_0=10.25) being much higher than the critical $F_{0.01,4,10}$ = 5.99.

Table (4.16). Analysis of Variance for the Flexural Strength.

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	F_0
Swarf Addition	1878.8	4	469.7	10.25
Error	458.285	10	45.28	
Total	2337.085	14		

Table (4.17) summarized the hypothesis testing of mean for the flexural strength test results and indicates the following points:

1) At a confidence level of (99.95%) the flexural strength of the no swarf concrete increased by (53.7%) compared to the required flexural strength of the design.
2) At a confidence level of (93.65%) the flexural strength of the 0.85-percent swarf concrete increased by (24.6%) compared to the no swarf concrete. It indicates at the same time at a confidence level of (99.95%) that the 0.85-percent swarf concrete increased by (91.6%) compared to the required flexural strength of the design.
3) At a confidence level of (65.14%) the flexural strength of the 1.7-percent swarf concrete increased by (8.1%) compared to the no swarf concrete. At the same time it indicates at a confidence level of (90.6%) that the flexural strength of the 1.7-percent swarf concrete increased by (41%) compared to the required strength of the design.
4) At a confidence level of (97.58%) the flexural strength of the 2.55-percent swarf concrete decreased by (36.3%) compared to the no swarf concrete. At the same time it indicates at a confidence level of (64.6%) that the flexural strength of the 2.55-percent swarf concrete decreased just by (2.06%) compared to the required strength of the design.

5) At a confidence level of (98.29%) the flexural strength of the 3.4-percent swarf concrete decreased by (19.0%) compared to the no swarf concrete. At the same time it indicates at a confidence level of (98.13%) that the flexural strength of the 3.4-percent swarf concrete decreased by (9.6%) compared to the required strength of the design.

Table (4.17). Analysis of Mean for the Flexural Strength Test Results.

Concrete Condition	Swarf Percentage %				
	0.0	0.85	1.7	2.55	3.4
Difference of Mean (t_0)*	$t_0 = 40.9$	$t_0 = 61.8$	$t_0 = 1.9$	$t_0 = -.45$	$t_0 = -5.43$
Difference of Mean (t_1)**	-	$t_1 = -1.97$	$t_1 = .436$	$t_1 = 2.83$	$t_1 = 3.287$

* t_0 = mean flexural strength with no swarf – mean flexural strength with swarf.

** t_1 = mean flexural strength with swarf – flexural strength of the design.

Depending on the previous results and the principles of the multiple regression that suggested by Hines and Montgomery (1990), the following regressions were constructed with correlation factors of (0.487 and 0.885) respectively:

$$Y_{9.1} = 50.9 - 0.36X - 2.54X^2 \text{ .... } (4.11)$$

$$Y_{9.2} = 46.147 - 15.68X + 21.96X^{1/3} \text{ .... } (4.12)$$

where:

$Y_{9.1}$ & $Y_{9.2}$ = the flexural strength (kg/cm^2).

X = swarf percentage (%).

The regression of ($R^2 = 0.885$) was shown graphically in figure (4.9).

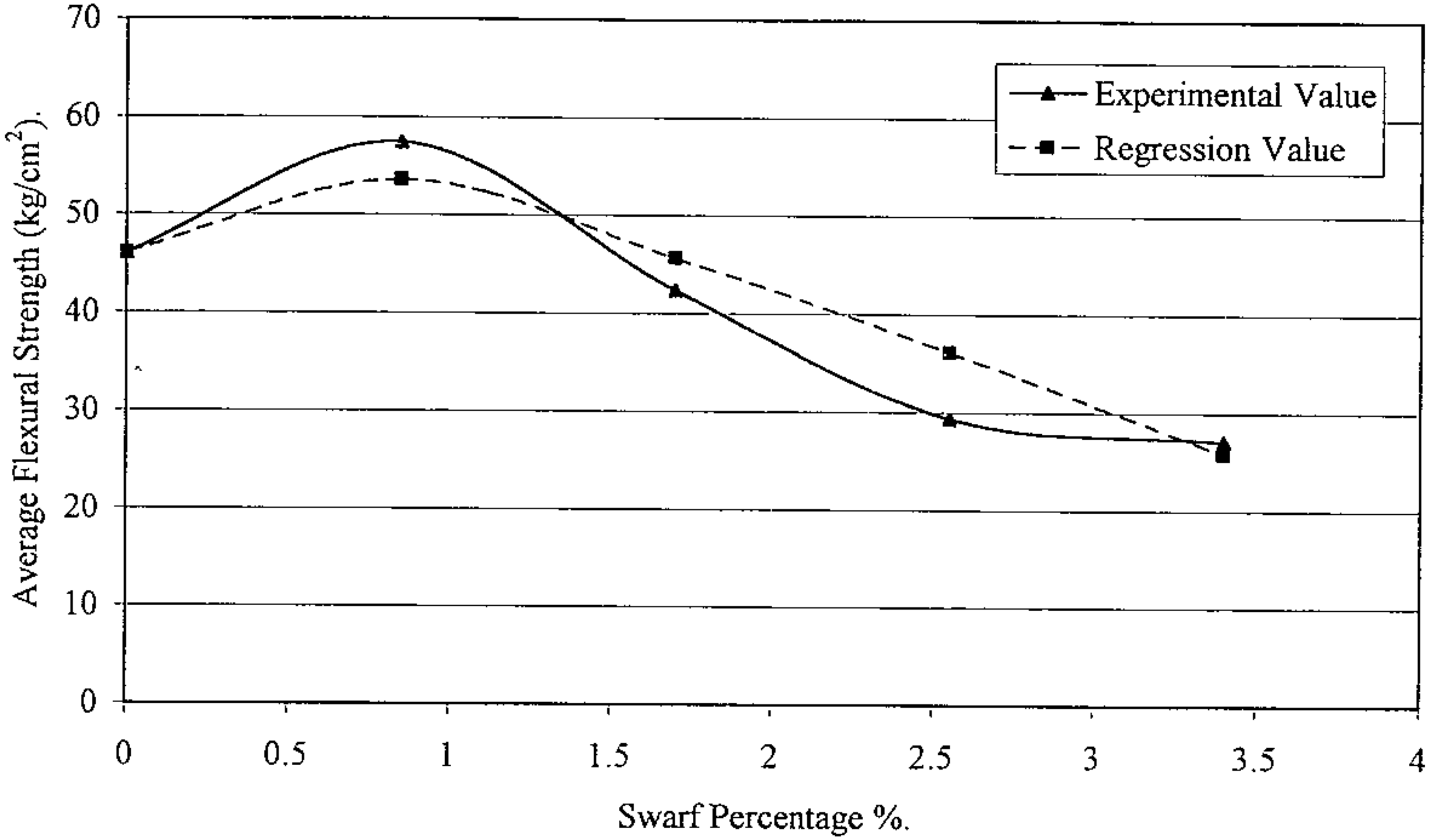


Fig (4.9).Relationship between Average Flexural Strength and Swarf Percentage.

4.3.6 Splitting Tensile Strength Test.

Results of the splitting tensile strength test which were shown in table (3.16), were graphically represented in figure (4.10).

It could be noted from the graph that the splitting strength of the swarf concrete are higher than its value of the no swarf concrete at some contents of swarf, and at other contents the splitting strength of the no swarf concrete exceed its value when the swarf is used.

It could be also observed that an increase in the swarf content is accompanied by an increase in the splitting strength up to a limit beyond which there is a reduction started to occur. A more detailed discussion of this phenomenon will be presented in the following sections.

Table (4.18) shows the analysis of variance for the splitting strength test results, which indicates by a comparison among the five different contents of the swarf at a confidence level of (99%) that the swarf content in the mix significally affects the average splitting tensile strength. This is reflected in its F-value (F0=12.9) being much higher than the critical $F_{0.01,4,10}$ = 5.99.

Table (4.18). Analysis of Variance for the Splitting Tensile Strength.

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	F_0
Swarf Addition	636	4	159	12.9
Error	123	10	12.3	
Total	759	14		

Table (4.19) summarized the hypothesis testing of mean for the splitting tensile strength and indicates the following points:

1) At a confidence level of (93.06%) the splitting tensile strength of the 0.85-percent swarf concrete decreased by (15.58%) compared to the no swarf concrete.
2) At a confidence level of (72.9%) the splitting strength of the 1.7-percent swarf concrete decreased by (7.6%) compared to the no swarf concrete.
3) At a confidence level of (98.45%) the splitting strength of the 2.55-percent swarf concrete decreased by (29.3%) compared to the no swarf concrete.
4) At a confidence level of (99.48%) the splitting strength of the 3.4-percent swarf concrete decreased by (34.12%) compared to the no swarf concrete.

Table (4.19). Analysis of Mean for the Splitting Tensile Strength Test Results.

Swarf Percentage %	0.85	1.7	2.55	3.4
Difference of Mean *	$t_0 = -1.9$	$t_0 = 0.677$	$t_0 = 3.39$	$t_0 = 4.58$

* Difference of Mean = mean splitting strength with no swarf – mean splitting strength with swarf.

Depending on the previous results, and the principles of the multiple regression analysis that suggested by Hines and Montgomery (1990), the following regressions were constructed with a correlation factors of (0.232 and 0.706) respectively, to combine the splitting tensile strength with the used swarf content:

$$Y_{10.1} = 37.94 - .887X - 1.412X^2 \quad \text{.........} \quad (4.13)$$

$$Y_{10.2} = 35.09 - 8.68X + 11.8X^{1/3} \quad \text{........} \quad (4.14)$$

where:

$Y_{10.1}$ & $Y_{10.2}$ = the splitting tensile strength (kg/cm^2).

X = swarf percentage (%).

The regression of (R^2 = .706) was represented in figure (4.10).

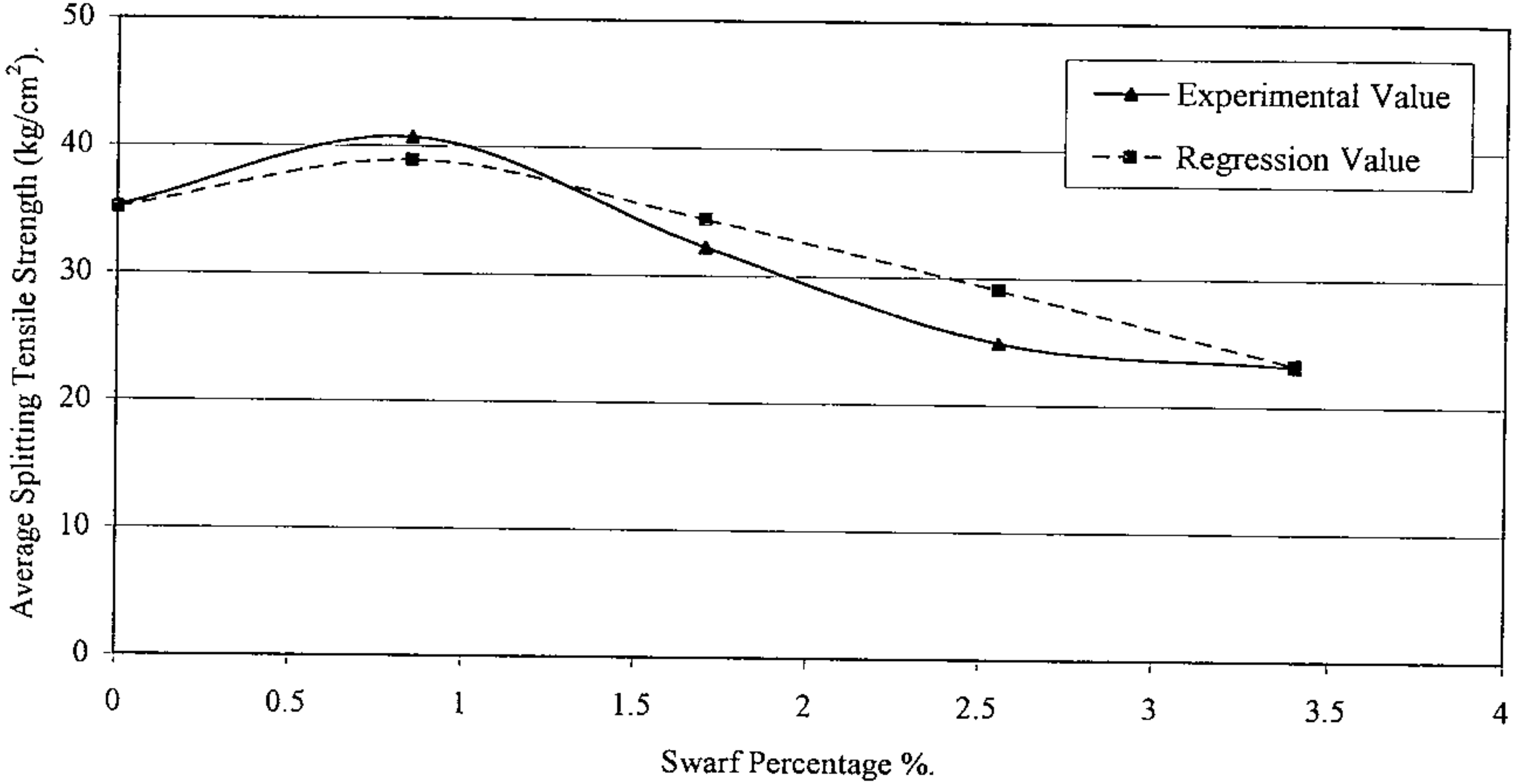


Fig (4.10). Relationship between Average Splitting Tensile Strength and Swarf Percentage.

4.4 Durable Concrete Results Analyses.

4.4.1 Concrete Penetration of Water.

Results of the water penetration test, which were shown in table (3.17), were graphically presented in figure (4.11).

It could be noted from the graph that the water penetration of the swarf concrete is simply higher than its value of the no swarf concrete. It could be observed that an increase in the swarf content is a compained by an increase in concrete penetration of water. A more detailed discussion of this phenomenon will be presented in the following sections.

Table (4.20) shows the analysis of variance for the water penetration test results, which indicates by a comparison among the five different contents of swarf at a confidence level of (72.5%), that the swarf content in the concrete mix simply affects the average rate of water penetration. This is reflected in its F-value (F_0=3.19) being simply higher than the critical $F_{0.275,4,10}$ = 1.42.

Table (4.20). Analysis of Variance for the Water Penetration Test.

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	F_0
Swarf Addition	561	4	140.25	3.19
Error	438.87	10	43.88	
Total	1000.24	14		

Table (4.21) summarized the hypothesis testing of mean for the water pernetration rate, and indicates the following points:

1) At a confidence level of (78.7%) the water penetration rate of the 0.85-percent swarf concrete

increased by (22.6%) compared to the no swarf concrete.

2) At a confidence level of (97.97%) the water penetration rate of the 1.7-percent swarf concrete increased by (74%) compared to the no swarf concrete.

3) At a confidence level of (95.2%) the water penetration rate of the 2.55-percent swarf concrete increased by (55.6%) compared to the no swarf concrete.

4) At a confidence level of (95.07%) the water penetration rate of the 3.4-percent swarf concrete increased by (115.7%) compared to the no swarf concrete.

Table (4.21). Analysis of Mean for the Water Penetration Rate Test Results.

Swarf Percentage (%)	0.85	1.7	2.55	3.4
Difference of Mean*	$t_0 = -0.936$	$t_0 = -3.08$	$t_0 = -2.194$	$t_0 = -2.15$

* Difference of Mean = mean penetration with no swarf – mean penetration with swarf.

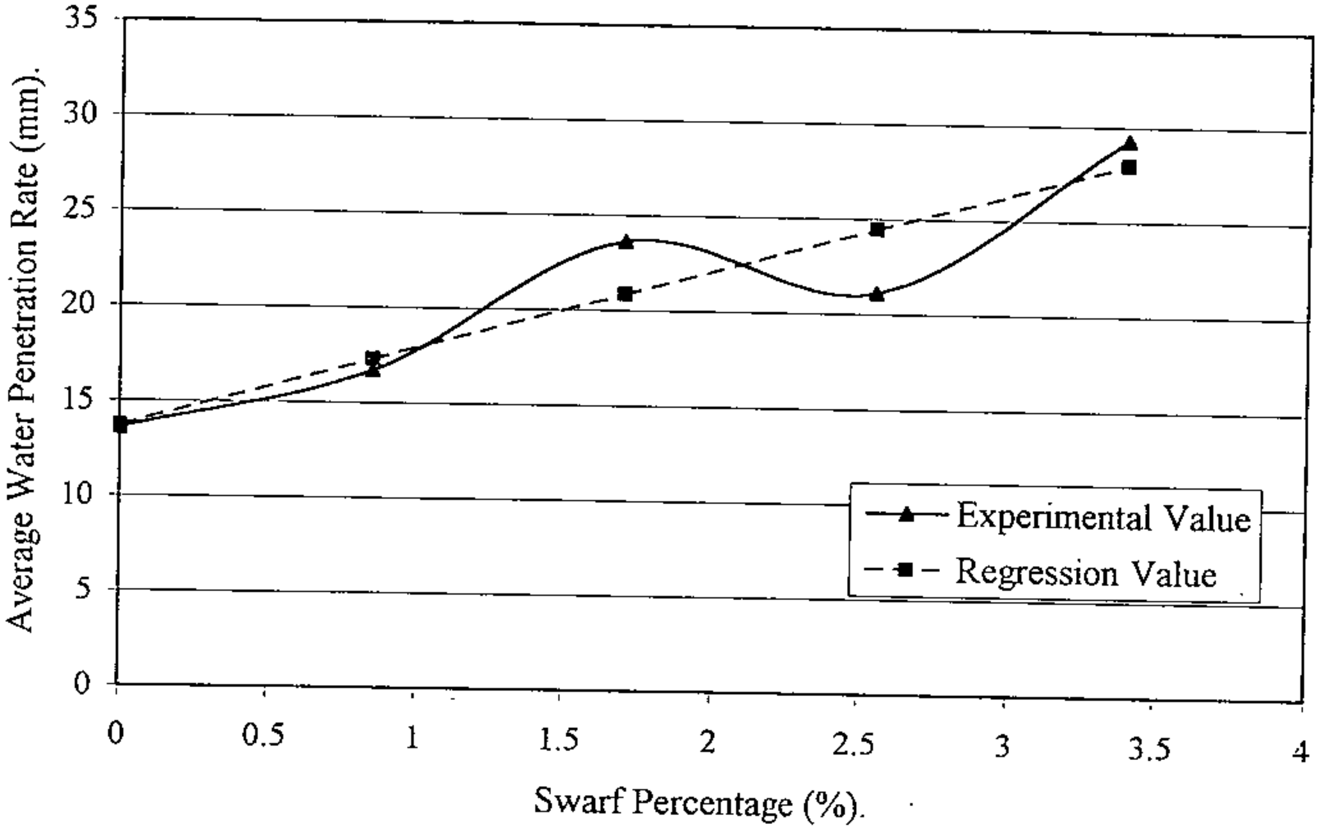
Depending on the previous results, and using the principles of the linear regression analysis that suggested by Hines and Montgomery (1990), the following regression, which is shown graphically in figure (4.11) was constructed with a correlation factor of (R^2 = 0.86), to combine the water penetration rate with the swarf content:

$$Y_{11} = 13.708 + 4.22X \quad \text{.........} \quad (4.15)$$

where:

Y_{11} = water penetration rate

X = swarf content (%).



Fig(4.11). Relationship between Average Water Penetration Rate and Swarf Percentage.

4.4.2 Concrete Penetration of Air.

Results of the air penetration that were shown in table (3.16), were graphically presented in figure (4.12).

It could be noted from the graph that an increase by the swarf content in concrete mix is compained by an increase in the air penetration. A more detailed discussion of this phenomenon will be presented in the following sections.

Table (4.22) shows the analysis of variance for the air penetration rate results, which indicates by a comparison among five different contents of the swarf at a confidence level of (72.5%) that the swarf content in the concrete mix simply affects air penetration rate. This is reflected in its F-value (F_0=3.08) being simply higher than the critical $F_{0.275,4,10}$ = 1.42.

Table (4.22). Analysis of Variance for the Air Penetration.

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	F_0
Swarf Addition	2.98×10^9	4	7.45×10^8	3.08
Error	2.417×10^9	10	2.417×10^8	
Total	5.4×10^9	14		

Table (4.23) summarized the hypothesis testing of mean for the air penetration rate, which indicates the following points:

1) At a confidence level of (78.5%) the air penetration rate of the 0.85-percent swarf concrete increased by (22.7%) compared to the no swarf concrete.
2) At a confidence level of (97.9%) that the air penetration rate of the 1.7-percent swarf concrete

increased by (74.1%) compared to the no swarf concrete.

3) At a confidence level of (95.17%) the air penetration rate of the 2.55-percent swarf concrete increased by (55.7%) compared to the no swarf concrete.

4) At a confidence level of (95.03%) the air penetration rate of the 3.4-percent swarf concrete increased by (115.78%) compared to the no swarf concrete.

Table (4.23).Analysis of Mean for Air Penetration Results.

Swarf Percentage (%)	0.85	1.7	2.55	3.4
Difference of Mean*	$t_0 = -0.927$	$t_0 = -3.055$	$t_0 = -2.176$	$t_0 = -2.14$

* Difference of Mean = mean penetration with no swarf – mean penetration with swarf.

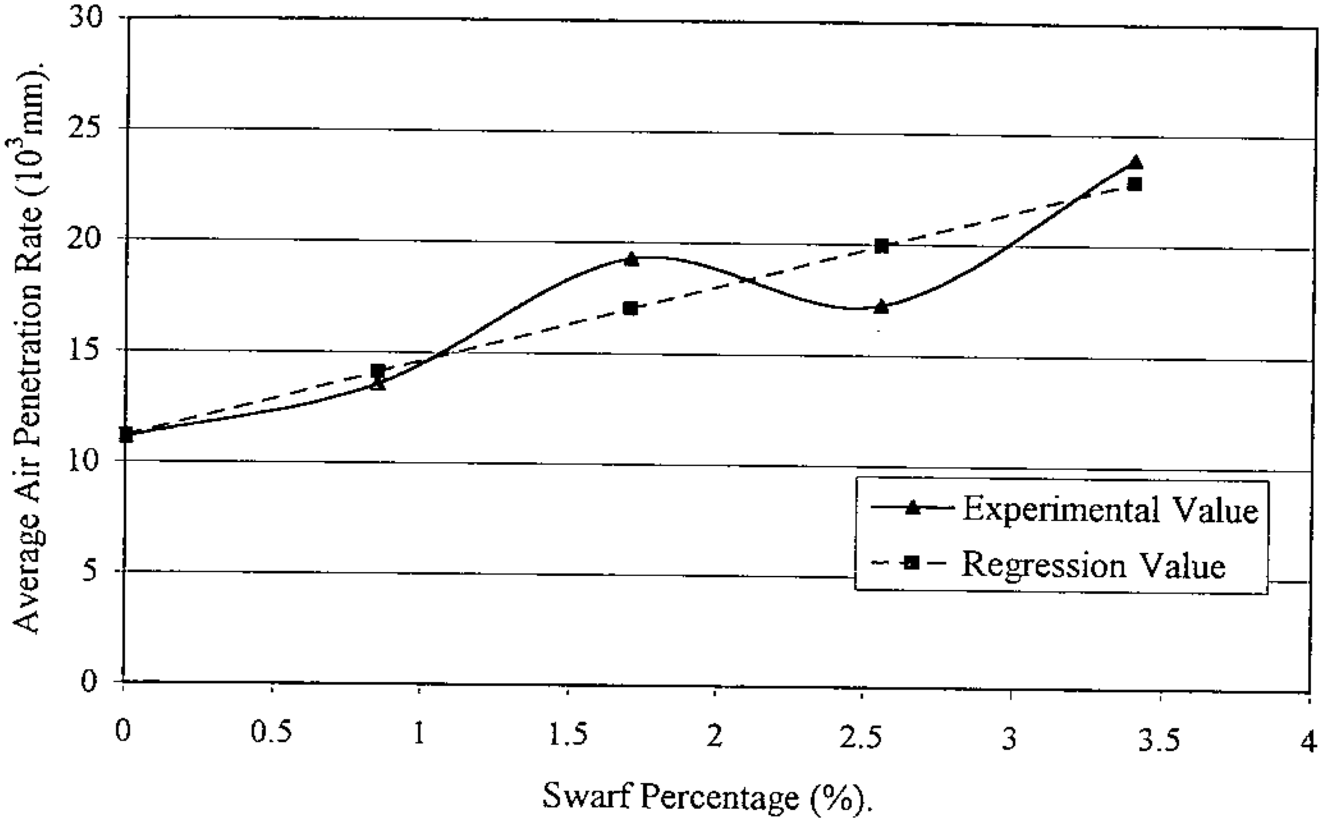
Depending on the previous results and the principles of the linear regression analysis that suggested by Hines and Montgomery (1990), the following regression that shown graphically in figure (4.12) was constructed with a correlation factor of ($R^2 = 0.862$), to combine the air penetration rate with the swarf content:

$$Y_{12} = 11.18x10^3 + 3.44x10^3X \quad \ldots\ldots\ldots \quad (4.16)$$

where:

Y_{12} = air penetration rate

X = swarf content (%).



Fig(4.12). Relationship between Average Air Penetration Rate and Swarf Percentage.

4.4.3 Skid Resistance.

Results of the skid resistance test, which were shown in table (3.18), were graphically presented in figure (4.13).

It could be noted from the graph that the skid resistance of the swarf concrete slabs is lower than its value of the no swarf concrete one. It could also be observed that an increase in the swarf content is compained by a reduction in the skid resistance. A more detailed discussion of this phenomenon will be presented in the following sections.

Table (4.24) shows the analysis of variance for the British Pendulum Number (BPN) test results, which indicates by a comparison among the five different contents of swarf, at a confidence level of (99%) that the swarf content in the concrete mix is significally affects the average British Pendulum Number (BPN). This is reflected in its F-value (F_0=349.5) being much higher than the critical $F_{0.01,4,15}$ = 4.89.

Table (4.24). Analysis of Variance for the British Pendulum Number.

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	F_0
Swarf Addition	4310.3	4	1077.58	349.5
Error	46.25	15	3.0833	
Total	4356.55	19		

Table (4.25) summarized the hypothesis testing of mean for the British Pendulum Number test results. It indicates at a confidence level of (99.95%) that the skid resistance of the concrete slabs that have a swarf content of (0.85%, 1.7%, 2.55% and 3.4%) decreased by (17.59%, 30.79%, 36.36% and 50.7%) respectively, compared to the no swarf concrete slab.

Table (4.25). Analysis of Mean for the British Pendulum Number Test Results.

Swarf Percentage (%)	0.85	1.7	2.55	3.4
Difference of Mean*	$t_0 = 12.43$	$t_0 = 21$	$t_0 = 25.68$	$t_0 = 33.5$

* Difference of Mean = mean BPN with no swarf – mean BPN with swarf.

Depending on the previous results and using the linear regression principles that suggested by Hines and Montgomery (1990), the following regression that shown in figure (4.13) was constructed with a correlation factor of (R^2 = 0.975), to combine the skid resistance with the swarf content:

$$Y_{13} = 82.65 - 12.06X \quad \text{..........} \quad (4.17)$$

where:

Y_{13} = the British Pendulum Number.

X = swarf content (%).

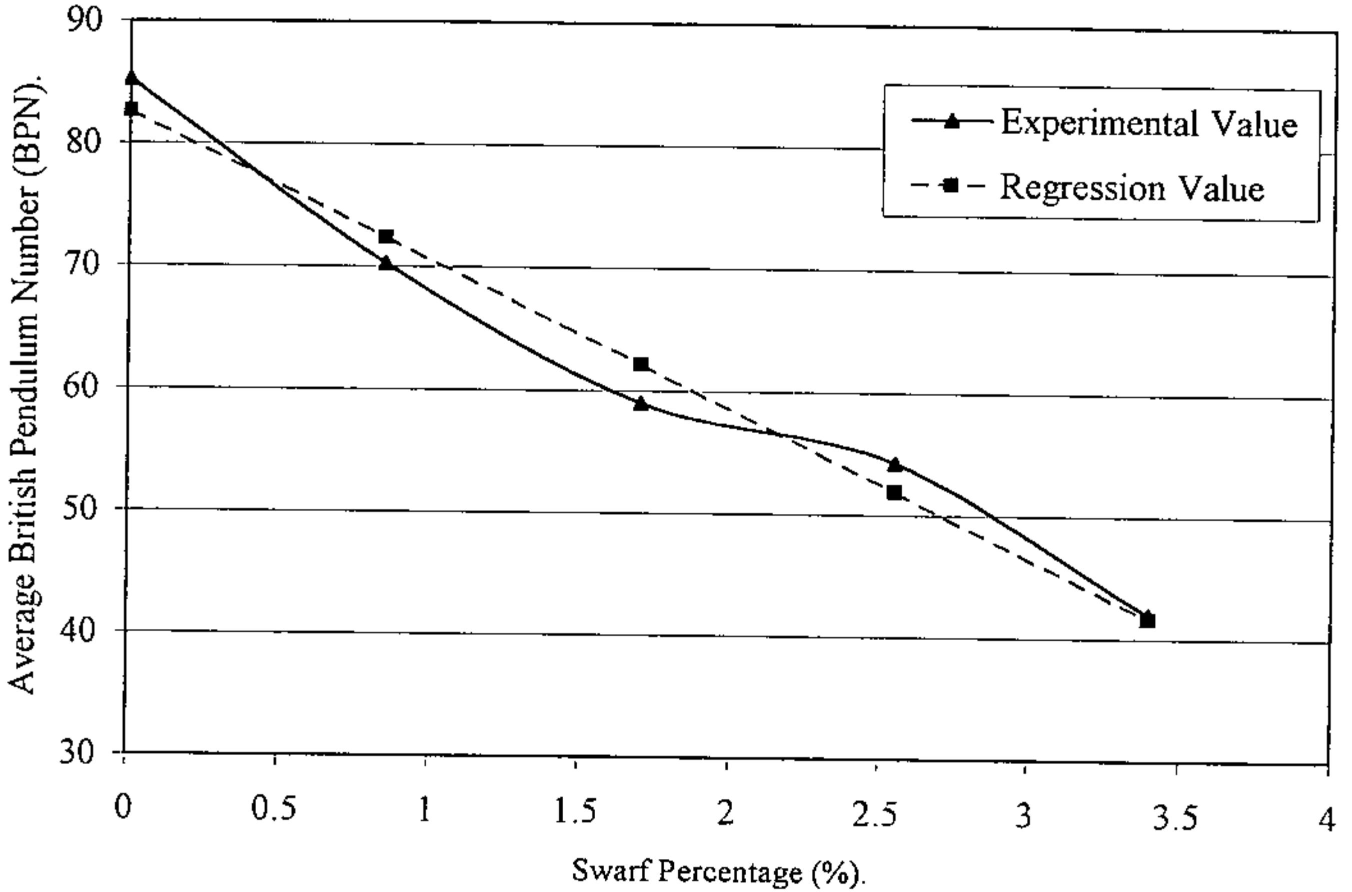


Fig (4.13). Relationship between Average British Pendulum Number and Swarf Percentage.

4.5 Discussion.

It is obvious from the previous analyses that the tests results were encouraging, that is, despite of the reduction which somewhat was caused to some of the concrete properties due to specified swarf contents, there were good quantitive and qualitive improvements in other properties. The following points will explain this opinion in details:

1) It was observed from the fresh concrete analysis that the workability property was improved when the steel swarf was added to the mix, up to some limits after which it started to decrease. But despite of the reduction at some contents of swarf, workability was still accepted with respect to the mix design requirements and the specification limits. Also, it could be noted that the maximum improvement in workability could be obtained at swarf content of (1.4%) of the mix weight, and by (170-180) % of the no swarf concrete workability.

The improvement in the workability can be justified due to the lubrication action of the swarf because of its texture, and the fine material action, so that consistency increased segregation and bleeding also was reduced. After a certain content (0.85%) the mix become non-homogenous and the workability decreases.

2) It was clear from the hardened concrete analyses that there was no improvement at any swarf content in the concrete compressive strength under the given mix design conditions (W/C = 0.5), and for the used material properties. However, the obtained compressive strength was still high enough compared to the desired strength of the design.

3) Hardened concrete analyses did not show substantial improvement due to swarf content in the concrete density.

4) It was observed that there was no improvement in the modulus of elasticity. This expected since the elasticity modulus is a function of the concrete compressive strength and density, which did not show substantial improvements due to swarf addition.

5) It was clear from the hardened concrete analyses that the flexural strength is significally improved. The addition of (0.85%) swarf increased the flexural strength by (25%) above its strength without a swarf addition. This ratio is the optimum swarf percentage for maximum flexural strength.

The maximum improvement of the flexural strength at a swarf content of (0.85%) means that the concrete efficiency in resisting cracks and pumping will be increased, the maintenance costs will be decreased and pavement life will also be increased.

The splitting results analyses also indicates that the concrete tension strength would be improved by (15%) of its value, when the swarf used with a content of (0.85%).

6) Despite of the simple increment in water and air penetration of concrete due to swarf content, analyses of variance for water and air penetration indicated that effect of swarf content on the concrete penetration of concrete, was significant only at a confidence level of (72.5%). This means that the swarf content has a simple action in increasing the concrete penetration. This was clear at a swarf content of (0.85%), which did not increase the concrete penetration more than (22.6%) compared to the no swarf concrete, at a confidence level of just (78.7%).

However, this simple increment in air and water penetration that was caused by the swarf content of (0.85%), can be controlled by several suggestions that will be discussed in chapter five.

7) It was clear from the skid resistance test analyses that the skid resistance was significally reduced by (50.7%) of its value compared to the no swarf concrete when highest swarf content of (3.4%) was used with the concrete mix. Nevertheless, the skid resistance was not reduced by more than (17.59%) of its value at the swarf content of (0.85%).

The reduction in the skid resistance due to the use of swarf in concrete mix, is still accepted for all types of sites. Since the British Pendulum Number (BPN) for the

0.85-percent swarf concrete was (70.25%) still align the British Road Research Laboratory requirements, that was sighted by Flaherty (1978) as shown in table (4.26).

Table (4.26). Suggested Minimum Values of Skid Resistance that Measured with the Portable Tester. (Flaherty, 1978).

Category	Type of Site	Minimum Skid Resistance (Wet Surface)
A	Difficult sites such as: • Roundabouts. • Bends with radius less than 150m on unrestricted roads. • Gradients, 1 in 20 or steeper, of lengths greater than 100m. • Approaches to the traffic lights on unrestricted roads.	65
B	Motorways, class one roads and heavily traffic roads in urban areas.	55
C	All other sites.	45

4.6 Economical Analysis.

Depending on the previous analyses, the following economical benefits can be suggested and obtained:

1) Concrete workability can be increased by (170-180)%, when the steel swarf content of (1.40%) is used. This means that the cost of the admixtures that is used to increase the workability (about 0.75 JD/m^3) can be saved.

2) Also water-cement ratio can be reduced to less than (0.5), which causes an increase in the compressive strength of the concrete, and at the same time the workability can be kept at the required level, depending

on the using of (0.85%) swarf content to compensate the reduction in water.

3) The improvement of (25%) that can be obtained in the flexural strength by using swarf content of (0.85%), could yield substantial saving in slab thickness design. This can be shown in the following simple analysis utilizing Bruce and Claikeson equation, which was sighted by Sharif (1982). The analysis showed that a reduction of (10.5%) in the slab thickness can be achieved:

$$d = (3W/S)^{1/2} \quad \ldots\ldots\ldots (4.18)$$

where:

d = the pavement slab depth.

W = the vehicle wheel load.

S = the concrete working stress.

then, for the same vehicle wheel load of (W):

$$d_1 = (3W/S_1)^{1/2} \quad \ldots\ldots\ldots (4.18.a)$$

$$d_2 = (3W/S_2)^{1/2} \quad \ldots\ldots\ldots (4.18.b).$$

By substituting of (S_2= 1.25 S_1) in equation (4.18.b) and dividing d_1 by d_2 then:

$$d_1 = 0.895\, d_2 \quad \ldots\ldots\ldots (4.18.c)$$

where:

d_1 = the pavement slab depth using a concrete of working stress S_1.

d_2 = the pavement slab depth using a concrete of working stress S_2.

S_1 = the concrete working stress. Without swarf.

S_2 = the concrete working stress using a swarf content

4) The reduction in the pavement slab depth by (10.5%) means that the average cost of the concrete cubic meter will be also reduced by (3.64 JD/m^3), that is, according to the local markets concrete of (270 kg/m^3) compressive strength has a unit price of (33 JD/m^3).

5) Joints spacing can be increased if (0.85%) steel swarf was added to the concrete mix.

6) The using of the 0.85-percent swarf concrete will reduce cracks, and the problem of pumping, which means a good saving in the maintenance costs.

7) The using of the 0.85-percent swarf concrete, will increase the life of the slab.

8) Concrete with no swarf can obtain a flexural strength of (36.5 kg/cm^2) at (14 day) age, but the 0.85-percent swarf concrete can obtain the same strength at the age of (8-9 days). This indicates that concrete pavements can be opened for traffic shortly after casting (8-9 days).

The previous results were concluded by using of the following equation, which suggested by Abbud (1992):

$$R_{28} = R_n (\log 28/\log n) \qquad \text{.........} (4.19)$$

where:

R_{28} = concrete strength at age of (28) day.

R_n = concrete strength at age of (n) day.

n = age of the concrete (day).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

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CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions.

1) Maximum workability can be obtained by using steel swarf content of (1.4%). Also, substantial improvement was achieved with the use of (0.85%) steel swarf, which means that the concrete compressive strength can be increased by reducing the water-cement ratio, and keeping the same level of the required workability.

2) Alternatively the increase in workability by using steel swarf of (0.85%) will substantially reduce concrete cost. This reduction might be reached to (0.75 JD/m^3) with the use of (1.4%) swarf content.

3) Segregation, bleeding and microcracks problems are expected to be reduced by using a steel swarf content of (1.4%) due to the reduction of the water content and the improvement of concrete workability.

4) Compressive strength, density, elasticity modulus and hammer test indicate that the use of swarf with concrete at some contents simply reduces their values, but approximately these values will still be accepted according to the standard requirements and conditions. On the other hand fresh concrete tests, which indicated that the workability could be kept at the design level,

besides reducing water-cement ratio, mean that compressive strength, density and elasticity of modulus can be improved when the water-cement ratio is reduced.

5) It is expected that there is no additional volumetric change stresses can be caused due to the using of swarf, because of the elasticity modulus stability.

6) Flexural and splitting tests proved that using 0.85-percent swarf concrete would improve the tensile strength by (15-25) %.

7) Using 0.85-percent swarf concrete can reduce the pavement slab depth by (10.5%), which means that the paving concrete cost can also be reduced by (3.46 JD/m^3).

8) Concrete roads can be opened to traffic shortly (8-9) day after casting by using 0.85-percent swarf concrete instead of 14 day, due to the early gain of the flexural strength expected.

9) The flexural strength improvement due to the swarf content may encourage the designers to use higher number of equivalent axial load without increase the pavement depth, which means that the working years of the pavement will be increased, also it may enable them to increase the joints spacing.

10) The reduction expected in the macrocracks and pumping problem due to the flexural strength improvement will reduce the maintenance costs.

11) Water and air penetration results indicate at low confidence level that the using of steel swarf with concrete at all the study contents simply increases the penetration values. But their properties are still statistically accepted at the low swarf content of (0.85%) and according to the German Standard Limits of Penetration.

12) Using steel swarf with concrete reduces the skid resistance of the slabs, but their properties will still be accepted at the swarf content of (0.85%) according to the British Road Research Laboratory requirements.

13) Swarf content must not exceed (0.85%), because some of the concrete properties start to deteriorate when the swarf content exceeds this percentage. Also, mixing must be homogenous enough and it must depend on using only the weighing proportioning not the volumetric proportioning.

5.2 Recommendations.

1) It is recommended to construct two trial strips of concrete pavement using swarf content of (0.0% and 0.85%) with there mix in order to check and compare their behavior structurally.

2) Further investigations are needed to examine the effects of using different aggregate gradations, different types of cement and different types of swarf.

3) Further experiments are recommended to examine the effect of using different water-cement ratios.

4) Further experiments on uncured samples using different contents of steel swarf may be carried out to study the effects of swarf on concrete curing.

5) Further investigation is recommended to examine the effect of steel swarf action in the resistance of concrete to sulfate attack.

6) Further experiments are recommended to examine the effect of steel in the resistance of concrete surfaces to impact and hardness.

7) Some tests were carried out on samples exposed to the local environment of Amman, Jordan. The study of effect of different environments encountered in the

Gulf regions and North Africa countries is suggested to be carried out under different temperatures and humidity contents.

8) It is recommended to provide adequate cross slope to the rigid pavement, which will increase its efficiency in water drainage, and minimize the water penetration. It also will substitute any reducing in the skid resistance that will be caused by using of swarf in concrete mix.

9) In order to ensure the achievement of desired improvements in concrete properties, it is recommended to provide the following requirements to prevent swarf corrosion:

- Concrete should possess an alkalinity of PH higher than ten, in order to prevent corrosion from occurring.
- Use anti-penetration admixture, expoxy or zinc-coated swarf and/or stainless steel swarf to prevent the corrosion.
- Potable water must be used in mixing to prevent the corrosion and other problems such as sulfate attack.

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ملخص

تحليل هندسي و إقتصادي لاستخدام برادة الحديد في الرصفات الخرسانية.

اعداد

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المشرف

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هنالك رغبة دائمة في تحسين الخواص الهندسية للرصفات الخرسانية بشكل عام، و بأقل كلفة ممكنة.و عنيت هذه الدراسة في إمكانية تحسين و رفع الخواص الهندسية للرصفات الخرسانية عن طريق إضافة برادة الحديد للخلطات الخرسانية.

كان أسلوب الدراسة المتبع لاستطلاع ذلك هو إجراء التجارب المخبرية و التحاليل الإحصائية لمعرفة مدى تأثر خواص الخرسانة الطازجة و الخرسانة الصلبة و ديمومة الخرسانة عند تحضير عينات خرسانية قياسية مضاف إليها برادة حديد بنسب (0، 0.85، 1.7، 2.55 و 3.4) % من وزن الخلطة الخرسانية الكلي. و لتحقيق هذا الأسلوب تم بداية تحديد الخواص الهندسية للمواد المستعملة في تحضير هذه الخلطات الخرسانية و هي (الماء، الأسمنت، الحصمى و برادة الحديد) بغرض تصميم خلطة خرسانية تحقق متطلبات التشغيل و المتانة و الديمومة.

دلت النتائج على انه بالإمكان تحقيق زيادة قصوى في تشغيل الخرسانة الطازجة بواسطة إضافة برادة الحديد بنسبة 1.4%. كما انه من الممكن زيادة مقاومة الثني و الانفلاق للخرسانة الصلبة بنسب (25 و 15) % على التوالي عند إضافة برادة الحديد بنسبة 0.85%.

كما أكدت النتائج على انه في نفس الوقت الذي لم يتحقق به أي تحسن في خواص الخرسانة الصلبة الأخرى مثل قوة الضغط و معامل المرونة و الكثافة و على معظم نسب البرادة المستعملة إلا أن التحليل الإحصائي للنتائج أكد بان مقدار ما تخسره بعض هذه الخواص عند بعض النسب من البرادة بقي مقبولا ضمن القواعد الإحصائية لقبول و رفض النتائج المخبرية.

أما فيما يتعلق بديمومة الخرسانة و التي تم استطلاعها بواسطة دراسة مقاومة السطح الخرساني للانزلاق و نفاذية الماء و الهواء، و قد أكدت النتائج المخبرية و التحاليل الإحصائية لها بأنه لم يطرأ أي تحسن

في هذه الخواص على الرغم من أنها بقيت مقبولة ضمن القواعد الإحصائية لقبول و رفض النتائج.

أن للحصول على تحسن في تشغيل الخرسانة الطازجة و زيادة مقاومة الخرسانة الصلبة للانزلاق و الثني بواسطة إضافة برادة الحديد بنسب معينة العديد من الفوائد و النتائج الاقتصادية الإيجابية و التي تم مناقشتها بالتفصيل. إلى جانب المردود البيئي الجيد بالتخلص من برادة الحديد في مجال مناسب وذلك لدورها في التلوث البيئي و الجوي.