WASTE PRODUCT UTILIZATION

IN HIGHWAY CONSTRUCTION AND MAINTENANCE

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This study was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

16. Abstract

The effects of utilizing large amounts of waste products in structural fills and highway base course applications were studied. Waste products investigated were fly ash/bottom ash, Donna Fill, cement kiln dust and brown mud. The physical properties used to determine the usefulness of the by-products were moisture/density relationships, compressive strengths, plasticity indexes, shrinkage limits, freeze thaw characteristics and gradations. The results indicated that mixes of 100 percent fly ash, 50 percent bottom ash - 50 percent fly ash, and 70 percent Donna Fill - 30 percent fly ash could economically be used as a construction alternate for stone course replacement with no loss to the integrity of the base course.

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WASTE PRODUCT UTILIZATION IN HIGHWAY CONSTRUCTION AND MAINTENANCE

by

E. W. LeFevre and M. M. O'Neal

FINAL REPORT

Transportation Research Project No. 92

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Arkansas State Highway and Transportation Department at the time of publication. This report does not constitute a standard, specification, or regulation.

July, 1986

GAINS, FINDINGS, AND CONCLUSIONS

The primary gains, findings, and conclusions of this study are as follows:

Within the limitations of the test procedures and for the materials used in this investigation, the following conclusions are made.

1. Current highway construction materials in base course and embankment construction can be replaced with waste product materials produced in Arkansas. The area of economical use is restricted by the haul distance from the source.
2. Construction material alternates, which are available in abundant quantities and have excellent laboratory performance are:

   100% Fly Ash

   50% Fly Ash - 50% Bottom Ash

   30% Fly Ash - 70% Donna Fill

   The aforementioned material(s) can be used as an construction alternate for stone course replacement with no loss to the base course integrity.

ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT

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IMPLEMENTATION STATEMENT

The results of this investigation indicate that current highway construction materials used in base course and embankment construction can be successfully replaced with waste product materials produced in Arkansas with no loss of structural integrity.

For construction projects within areas of economically available waste products identified in this report, the Arkansas State Highway and Transportation Department should allow these materials as alternates in structural fill and base course construction. The alternates should include 100% fly ash, 50% fly ash - 50% bottom ash, and 30% fly ash - 70% Donna Fill. Such a change should be accompanied by specifications for a strict quality control program designed to assure the proper placement of the material.

The use of the waste products should provide competitive alternates within an area of economical use.

This implementation statement was approved by the Research Subcommittee at a meeting on August 15, 1986.

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Chapter One

INTRODUCTION

The utilization of large amounts of waste products in highway construction or maintenance would both dispose accumulating by-products and conserve natural resources such as land and stone. Of the abundant waste products, four that are available and have had limited usage are:

1. Fly ash/Bottom ash: a by-product of coal fired power plants.
2. Donna Fill: a by-product of syenite quarrying.
3. Kiln Dust: a by-product of the portland cement industry.
4. Brown Mud: a by-product of aluminum production.

The four materials possess varying highway construction applications, and investigation of the selected materials was suggested by the Arkansas State Highway and Transportation Department. The sources of the materials are shown geographically in Figure 1.

The determination of by-product utilization is dependent on basic engineering properties. The following tests were conducted to provide necessary information on the by-product's physical characteristics.

1. Moisture/Density Relationships
2. Compressive Strength
3. Plasticity Index/Shrinkage Limit
4. Freeze Thaw Characteristics
5. Gradation

Although investigation of physical properties give insight to an ultimate application, only practical and economical utilizations are desirable. To prevent compiling of redundant data, considerations were given to product availability, unit cost, and geographical location of the source.

Waste product evaluation of the four materials and selected mixtures are presented within this report. The following mixes were chosen for analysis.

Fly ash with 70, 80, and 90% Donna Fill

Fly ash with 70, 80, and 90% Brown mud

Fly ash with 50, 60, and 70% Bottom ash

Bottom ash with 70, 80, and 90% Donna Fill

Bottom ash with 70, 80, and 90% Brown mud

Because of product availability and geographical compatibility, fly ash and bottom ash were combined with Donna Fill and brown mud. Kiln dust was not chosen for any mixtures due to its remoteness with respect to the other materials. Mixture percentages were chosen to predict an optimum blend within an economical range.

Numerous applications in highway construction are possible for all the materials mentioned. However, this report will focus on structural fills and base course applications.

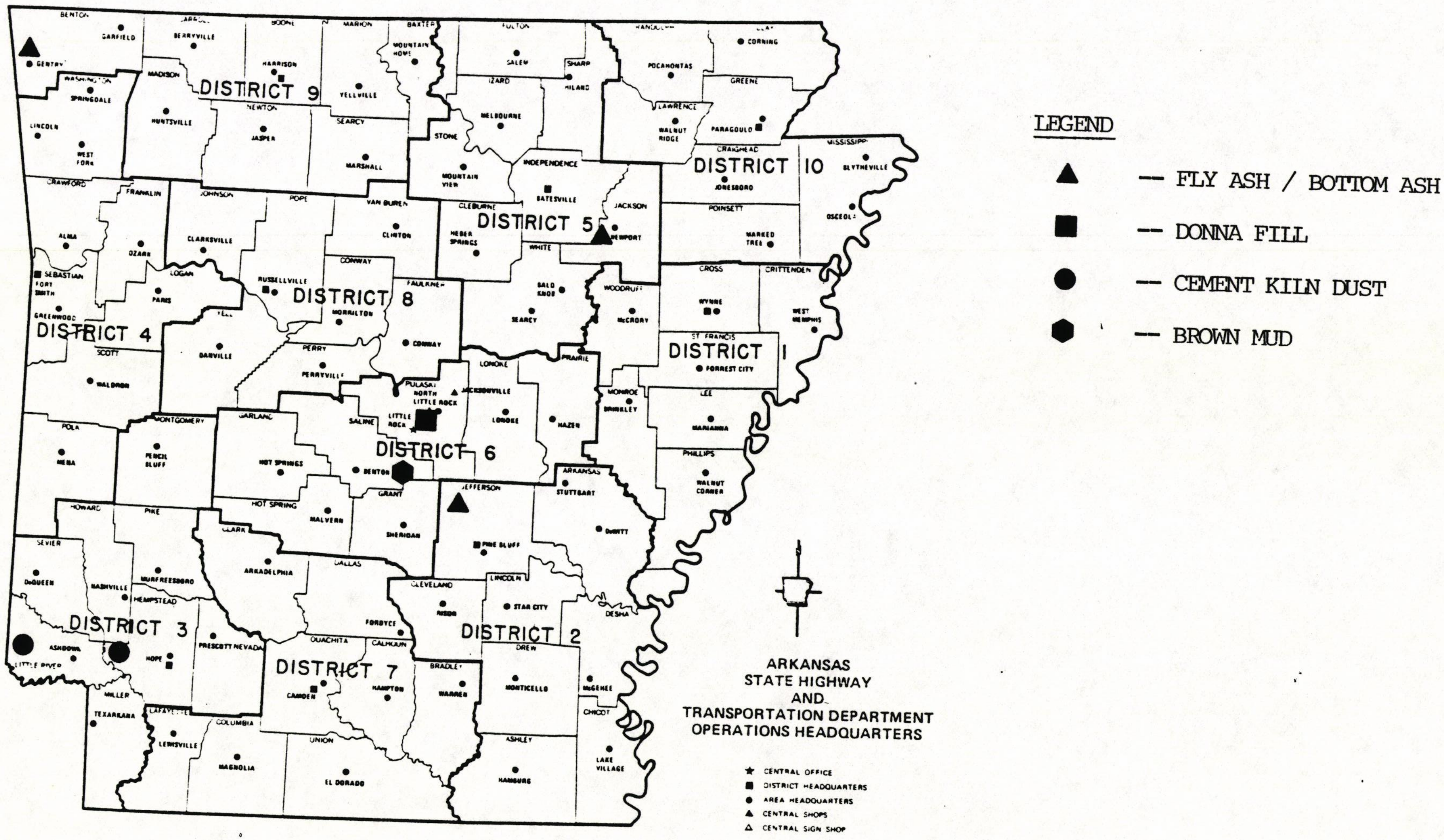

FIGURE 1. AREAS OF BY-PRODUCT AVAILABILITY

Chapter Two

BACKGROUND INFORMATION

Fly ash/Bottom ash

Coal fired electric generating plants simultaneously produce fly ash and bottom ash. Upon the ignition of pulverized coal in the burning chamber, two types of ash are produced which have roughly the same chemical composition. Bottom ash, ash particles or slag in which 80 percent of the material is retained on the number 200 sieve, falls to the bottom of the burning chamber. Fly ash, which remains suspended in exhaust gases, is removed by electrostatic precipitators. Ninety percent of the fly ash passes the number 325 sieve[1].

Typical chemical compositions for the ashes are listed below:

Parameter	Fly Ash	Bottom Ash
Silicon Dioxide (SiO_2),%	35-40	50-55
Aluminum Oxide (Al_2O_3),%	25-30	15-20
Iron Oxide (Fe_2O_3),%	5-10	3-5
Calcium Oxide (CaO),%	20-25	10-15
Magnesium Oxide (MgO),%	5-10	<5
Sulfur Trioxide (SO_3),%	<2	<1

Fly ash, technically termed a pozzolan, is a siliceous or siliceous and aluminous material which when combined with calcium hydroxide and moisture form a stable cementitious compound[2]. Within the last 10 years numerous fly ash investigations have been conducted.

A report, conducted by the University of Arkansas in 1980 for the Arkansas State Highway and Transportation Department, studied the properties of self-hardening fly ash and its use as a soil stabilizing agent for clays and sands. The study concluded fly ash produced in Arkansas from Wyoming low sulfur coal could be used as a soil stabilizing agent. Compressive strengths of 1800 psi were achieved for an 80% sand and 20% fly ash mixture when compacted immediately after mixing. Effects of compaction delay were also studied; with two hours delay, over a third of the strength was lost and with four hours delay, the loss was over half. Gypsum and some commercial concrete retarders were found effective in reducing the detrimental effect of delayed compaction. A field test, at Southwestern Electric Power Company's Flint Creek power plant in Gentry, Arkansas, was conducted to determine the effectiveness of equipment and procedures in soil-fly ash construction. The report concludes that self hardening fly ash can be used to stabilize road bases, and stabilization works best in sands and clays because of a better mechanical interlock between soil particles. Adequate mixing of the fly ash and rapid compaction of the matrix were found to be important and necessary parameters in field construction of the stabilized bases[17].

In the early 1980's, the Arkansas State Highway and Transportation Department experimented with various fly ash applications. A 100% fly ash base course was constructed near the Pine Bluff expressway. Findings from the field test concluded that it is possible to have a base course of 100% fly ash. From the construction of the road base, the following conclusions and comments were made:[3]

1. Material should be placed in one (1) layer.
2. Construction process from adding water to rolling took approximately 22 minutes.
3. Specified time lapse of seven (7) days without traffic was unnecessary.
4. Inconsistencies in fly ash made working with it difficult.
5. Curing did not appear to be a problem.
6. Shrinkage cracks did not appear to be a problem.

During the Spring of 1985, the Federal Highway Administration, State highway agencies, and the American Coal Ash Association co-sponsored a series of four seminars across the United States on the subject of fly ash in highway construction. A publication, consisting of 18 papers presented at the seminars, presents practical guidance on fly ash use in various applications including portland cement concrete and stabilized aggregate bases[18].

<u>Donna Fill</u>

Donna Fill, a registered trademark, is a waste product obtained from the production of fine nepheline syenite granite rock granules which are used to coat asphalt tile roofing. The material consists of the fraction of crushed rock passing the number 10 sieve[4].

Donna Fill is an excellent construction material because of its angular particles and mineral constituents. The material is angular due to fracturing of the granite during the crushing operation. Interlocking of the angular particles gives the material its strength when properly placed. Granite is primarily composed of quartz and feldspar. Both minerals are hard, durable and highly resistant to mechanical and chemical weathering.

Donna Fill has been used in and around central Arkansas for many years to increase the shear strength of soft soils, to bridge swamps for highway construction, to improve subgrade material under runways, taxiways and interstate highways, and as a fill material under railroad beds in soft clayey soils. From independent laboratory investigations plate load tests of Donna Fill foundations over poor soil have reached 8,000 to 10,000 pounds per square foot with settlements of less than 0.1 inches. Although the number of tests which were performed at one moisture content were limited, the plate load test indicates a significant bearing capacity increase.

An investigation conducted at the University of Arkansas at Fayetteville concludes that Donna Fill is a fair to good foundation material for flexible pavements. California Bearing Ratio tests give values of 12 percent at 0.1-inch penetration. The results of the R-value tests, however, indicate that Donna Fill, with an average R-value of 74, is a excellent material for use as a base or subbase material. Low CBR values were blamed on these small penetration (1.95 inches diameter) and the low surcharge (10 pounds) placed on the samples during penetration[4].

An investigation conducted by D. N. Little, Ph.D., found CBR values in excess of 100 percent when specified grading requirements are met. For fine grained Donna Fill (AASHTO A-2-4), CBR values of 40-45 percent were achieved. The report also investigated stabilizing Donna Fill with portland cement, lime-fly ash or asphalt. It was concluded that the stabilized form of Donna Fill substantially improved the structural properties such that it was acceptable for use in virtually any base course.

Kiln Dust

Cement kiln dust originates when finely-ground raw materials become air borne in the stream of combustion gases traveling up the kiln during the production of portland cement. A general chemical analysis is given below. Note that the dust varies greatly in composition and other chemicals may also be present in small amounts.

Parameter		Percentage
Iron Oxide	(Fe_2O_3)	<2
Aluminum Oxide	(Al_2O_3)	<5
Magnesium Oxide	(Mg)	<1
Calcium Oxide	(CaO)	30-50
Silicon Oxide	(SiO_2)	10-15
Sodium Oxide	(Na_2O)	0-5
Sulfur Oxide	(SO^3)	10-20

The Federal Highway Administration and the U.S. Department of Energy has recently conducted an 18-month laboratory investigation on kiln dust. The investigation was conducted to determine the effectiveness of substituting kiln dust in place of hydrated lime in lime/fly ash/ aggregate road base mixes. Reportably, the kiln dust equaled or bettered the performance of current lime additions in durability and volume stability characteristics. Tests and field performance show that kiln dust/fly ash/aggregate mixes gain compressive strength with time to 2,000-3,000 psi[5].

Another area, in which kiln dust shows possible highway construction applications, is partial replacement of cement in structural concrete. Results of such an investigation shows that for the same workability concrete, cement can be replaced by up to 15 percent with cement kiln dust. The results showed that the kiln dust as a cementitious material retards the setting of concrete; however, increases in water demand for a constant consistency and a decrease in compressive strength were noted[6].

Brown Mud

Brown mud is a waste by-product of the alumina industry unique to central Arkansas. Aluminum is extracted from bauxite ore by a reduction method termed the Bayer Process. The process digests bauxite ore with caustic soda to extract alumina that is present in the ore as gibbsite (Al_2O_3 $3H_2O$). Also prevalent in the Arkansas bauxite ore and not affected by the Bayer Process, are aluminum silicate and other desilication products which are subsequently processed by adding limestone and soda ash before firing in a kiln. Soluble sodium aluminate is removed by leaching, and insoluble dicalcium silicate (called "brown mud" or "brown lime") is filtered and pumped to a waste lake where it is dried and collected. After collection, the brown mud is processed by mechanically reducing and/or screening the dried material. The amount of processing is determined by the buyer; however, material price increases with the amount of processing.

This insoluble "brown mud" contains lesser quantities of iron, aluminum, titanium and sodium oxides; its calcium carbonate equivalent varies from approximately 70 to 90 percent[11].

Information on brown mud research or development in highway base course construction was unattainable. However, the use of brown mud as a stabilizing agent has been discussed and investigated. An unpublished report by the Arkansas State Highway and Transportation Department indicates the material has possible highway construction applications.

The Arkansas State Highway and Transportation Department report concluded brown mud could be used as a stabilizer for gravels or silty soils where a large reduction of plasticity index is not desired. The report also suggested possibilities of brown mud as a light-weight fill material particularly across swamps and water areas, where a light-weight material with a high optimum moisture content is desired[11].

Chapter Three

LABORATORY INVESTIGATION

General Test Plan

The intent of the tests is to determine if select waste products will meet current highway material specifications. The following AASHTO test standards were used.

Moisture/Density Relationship	AASHTO	T99
Compressive Strength (7 day unconfined)	AASHTO	T208
Plasticity Index/Shrinkage Limit	AASHTO	T90/T92
Freeze Thaw Characteristics	AASHTO	T136
Particle Size Analysis	AASHTO	T88

Laboratory tests provide for correlating and/or predicting actual field performance of the waste products. Also, comparisons of product performance to current construction materials and future material investigations are made possible.

Source of Material

The materials as described in Chapter 2 were obtained from the following sources:

Chem-Ash, Incorporated of Redfield, Arkansas provided the fly ash and bottom ash. Arkansas Power and Light's White Bluff Generating Plant is the Chem-Ash source.

Central Arkansas crusher plants are the source of Donna Fill. The material is handled by the Donna Fill Company of Little Rock, Arkansas.

Two companies located in southern Arkansas provided cement kiln dust: Arkansas Cement Corporation of Forman and Ideal Basic Industries of Saratoga.

Brown mud was produced and provided by Alcoa's aluminum processing plant in Bauxite, Arkansas.

Personnel from the Arkansas State Highway and Transportation Department sampled, collected and delivered the waste by-products to the University of Arkansas's Civil Engineering Laboratories in Fayetteville.

<u>Method of Test</u>

First, the plasticity index of the materials and mixes were determined. The test provided insight as to how the material would perform and react to water and handling. The test was performed in accordance with AASHTO T90. Shrinkage limit specimens were taken simultaneously with liquid limit test per AASHTO T92 specifications. Upon completion of the plasticity test, fly ash and kiln dust were noticeably affected by the hydration of water. Both materials exhibited a temperature increase and became less workable. The hydration process caused the fly ash and kiln dust to begin setting after 30 to 45 minutes.

Next, moisture/density relationships were determined to provide the optimum moisture content necessary for the remaining tests. All materials and mixes, excluding the ones with fly ash and kiln dust, were compacted according to AASHTO T99 (Standard Proctor). Specimens containing fly ash and kiln dust were compacted in the same manner; however, a time delay of 30 minutes was used. An actual time delay of 20-25 minutes was used previously for mixing and placing a 100% fly ash base course[3].

Unconfined compression specimens were compacted using the same procedure and mold (4"dia, 1/30th cubic foot) as in the moisture density specimens. Compression tests were conducted on a 60 kip capacity universal testing machine. Tests were performed according to AASHTO T208. Mixtures which did not have adequate cohesion were excluded.

Freeze thaw specimens were compacted simultaneously with the compression strength test specimens. The test was performed according to AASHTO T136 with the exception of the freezer temperature. A required freezer cabinet temperature of -10°F is specified; however, the available freezer had a minimum temperature of -1°F. The higher freezer cabinet temperature was not considered to be a harmful factor. In Chapter Four, the freeze thaw test results show the specimens exhibited either excellent or poor performance, and a larger temperature differential would probably be necessary to change the results significantly.

With the exception of brown mud, all particle size analysis were provided by the production or handling companies. Reports of tests were conducted for the companies by either independent testing laboratories or the Arkansas State Highway and Transportation Department. Analysis of the brown mud was made in the Civil Engineering laboratory at Fayetteville, Arkansas in accordance with AASHTO T88 specifications.

Chapter Four

TEST RESULTS

Moisture/Density Relationship

Dry densities for the materials and mixes ranged between 66 and 117 pounds per cubic foot. Brown mud was the lightest. A mixture of fly ash and Donna Fill was the heaviest. Optimum moisture contents ranged from 4 to 42 percent. Moisture/Density relationships are shown in Table 1 and curves are presented in Appendix D.

Compressive Strength

Compressive strengths ranged from 90 to 815 pounds per square inch. Unconfined compressive strengths are listed in Table 2. Fly ash and kiln dust specimens achieved the highest strengths; however, the tabulated results are not representative of the material's full capacity. Fly ash strengths of 5,000 to 6,000 psi and kiln dust strengths of 900 to 1,000 psi are realistically achievable [2, 10]. End failures of the specimens occurred before the full capacity of the material could be reached. All other mixes demonstrated conical or vertical shear failures.

Plasticity Index/Shrinkage Limit

Fly ash and kiln dust were the only materials found to be plastic. As discussed in Chapter 3, these two materials become less plastic with time until the materials finally achieved set. Physical properties of the individual materials and mixtures are listed in tables 3 thru 6. All materials exhibited no significant volume change during the shrinkage limit test.

Freeze Thaw Characteristics

Fly ash and fly ash/Donna Fill mixes exhibited excellent freeze thaw durability with cement weight loss less than two percent. Maximum acceptable limits for the two mixes are 10%.[16] The 50% fly ash-50% bottom ash mixture also performed well with a cement weight loss less than 3%. Mixes with brown mud performed poorly with weight loss in excess of 50%. Freeze thaw results are listed in Table 7 and performance criteria in Table 8.

Gradation

Fly ash and kiln dust were classified as a silty soil. Bottom ash and brown mud were classified as a fine sand. Donna Fill, a non-plastic material, could be classified as either a fine sand or silty gravel sand. Soil classifications and gradations are given in Table 3 for the individual materials and in Tables 4-6 for the mixes.

Table 1. Moisture/Density Results

Material or Mix	Optimum Moisture (%)	Dry Density (pcf)
Fly Ash	14	109
Bottom Ash	7	81
Donna Fill	9	100
Kiln Dust	27	87
Brown Mud	42	67
Fly Ash & Bottom Ash		
30/70	5	106
40/60	6	108
50/50	4	112
Fly Ash & Donna Fill		
10/90	7	111
20/80	8	113
30/70	11	117
Fly Ash & Brown Mud		
10/90	40	70
20/80	41	75
30/70	38	80
Bottom Ash & Donna Fill		
10/90	6	99
20/80	6	96
30/70	4	94
Bottom Ash & Brown Mud		
10/90	41	66
20/80	37	68
30/70	40	69

Table 2. Unconfined Compression Results

Material or Mix	Unconfined Compression Strength (psi)
Fly Ash	815
Kiln Dust	665
Fly Ash & Bottom Ash	
30/70	150
40/60	350
50/50	530
Fly Ash & Donna Fill	
30/70	445
Fly Ash & Brown Mud	
20/80	90
30/70	100

Table 3. Individual Materials: Physical Analysis

Parameter	Fly Ash	Bottom Ash	Donna Fill	Kiln Dust	Brown Mud
Liquid Limit	20%	-	-	36%	-
Plastic Limit	14%	-	-	28%	-
Plasticity Index	6%	Non-Plas.	Non-Plas.	8%	Non-Plas.
Amount Passing No. 10	-	80%	100%	100%	100%
Amount Passing No. 40	-	55%	85%	100%	70%
Amount Passing No. 200	-	20% Max	20%	70%	10%
Amount Passing No. 325	90%	-	-	-	-
AASHTO Soil Class.	A-4	A-3	A-2-4	A-4	A-3

Table 4. Fly Ash & Bottom Ash Mix: Physical Properties

	Proportioning (fly ash/bottom ash) 30/70	40/60	50/50
Plasticity Index	Non-Plastic	Non-Plastic	Non-Plastic
Amount Passing No. 10	85%	90%	90%
Amount Passing No. 40	70%	75%	80%
Amount Passing No. 200	45% max	50% max	60% max
AASHTO Soil Classification:	A-4	A-4	A-4

Table 5. Fly Ash & Donna Fill: Physical Properties

	Proportioning (fly ash/Donna Fill) 30/70
Plasticity Index	Non-Plastic
Amount Passing No. 10	100%
Amount Passing No. 40	100%
Amount Passing No. 200	35%
AASHTO Soil Classification:	A-2-4 or A-4

Table 6. Fly Ash & Brown Mud: Physical Properties

	Proportioning (fly ash/brown mud) 10/90	20/80	30/70
Plasticity Index	Non-Plastic	Non-Plastic	Non-Plastic
Amount Passing No. 10	100%	100%	100%
Amount Passing No. 40	70%	70%	75%
Amount Passing No. 200	20%	30%	40%
AASHTO Soil Classification:	A-2-4	A-2-4	A-2-4

Table 7. Freeze Thaw Results*

Material or Mix	Cement Loss (%)	Volume Change (%)
Fly Ash	1.4	0.1
Kiln Dust	18.3	4.4
Fly Ash & Bottom Ash		
30/70	25.3	0.5
40/60	6.7	0.4
50/50	2.4	0.3
Fly Ash & Donna Fill		
30/70	1.3	0.2
Fly Ash & Brown Mud		
20/80	>50	7.0
30/70	>50	6.6

*Data given for end of 12^{th} cycle
Specimens molded @ optimum moisture as given in Table 1.

Table 8. A.H.T.D. Soil Cement Freeze Thaw Criteria*

Group No.	AASHTO Soil Classification	Percent Weight Loss @ 12^{th} cycle
1	A-1, A-2-4, A-2-5 A-3	14%
2	A-2-6, A-2-7, A-4, A-5	10%
3	A-6, A-7	7%

*Portland Cement Association Documents

Material(s) Performance Summary

For base course or embankment construction, a material must exhibit certain physical properties. The properties studied within this report include workability, durability and strength. Performance of the waste material(s) are summarized below.

Fly Ash - The fly ash is workable with a plasticity index of 6% (30 minute time delay). The material has a clayey consistency and becomes more difficult to work as its pozzolanic reaction progresses. Excellent freeze thaw results were exhibited and laboratory compressive strength test in excess of 800 psi were achieved.

Kiln Dust - The kiln dust has approximately the same workability as the Fly Ash; however, cement weight loss in excess of 15% surpasses the allowable. Laboratory compressive strength test in excess of 650 psi were achieved.

Bottom Ash, Donna Fill & Brown Mud - These three materials were all non-plastic and unable to "set up" for durability and strength tests.

Fly Ash/Bottom Ash Mixes - All combinations were non-plastic and were very workable. The 50/50 mixture proved most efficient with cement weight loss less than 3% for the freeze thaw test and laboratory compressive strength in excess of 500 psi.

Fly Ash/Donna Fill Mixes - Exhibited the same workability as the

Fly Ash/Bottom Ash mixes. The 70% Donna fill - 30% Fly Ash proved most efficient with cement weight loss less than 2% for the freeze thaw test and a laboratory compressive strength approximately equal to 450 psi.

Brown Mud/Fly Ash & Bottom Ash Mixes - All combinations were non-plastic. Brown Mud mixtures with Bottom Ash were non-cohesive and could not be tested for durability and strength. Fly Ash combinations exhibit poor durability (greater than 50% weight loss) and poor strength (less than 100 psi).

The following materials are recommended for highway construction alternates as discussed in later chapters.

100% Fly Ash

50% Fly Ash - 50% Bottom Ash

30% Fly Ash - 70% Donna Fill

Product availability, unit cost, geographical location and performance indicate that a practical and economical utilization is possible for the aforementioned materials.

Chapter Five

DISCUSSION AND RECOMMENDATIONS

Pavement Design Considerations

Pavement design, as applied to flexible pavement structures is based on the AASHTO Interim Guide published in 1972. The design procedure presented in the AASHTO guide is in terms of a structural number (SN). The structural number is an abstract number expressing the structural strength of pavement required for a given combination of soil support values, total equivalent 18-kip single-axle loads, terminal serviceability index and regional factor[14]. The required SN is converted to actual thickness of surface, base and sub-base courses by means of a layer coefficient representing the relative strength of the material. Once a minimum SN is determined the following equation is used to relate material strength with required layer thickness.

$$SN = a_1D_1 + a_2D_2 + a_3D_3$$

where a_1, a_2, a_3 = layer coefficients representative of surface, base and sub-base course.

D_1, D_2, D_3 = actual thickness, in inches, of surface, base, and sub-base courses, respectively.

Pavement layer coefficients vary from state to state and depend on the physical properties of the material. A normal range of design coefficients are[14]:

Pavement Layer	Design Layer Coefficient
a_1 - Asphalt surface	0.44
a_2 - Crushed stone base course	0.14
a_3 - Sandy gravel sub-base course	0.11

Obviously, layer a_2 is of interest to this report, and based on comparative strength test a layer coefficient can be assigned to the pozzolanic base course. This in effect gives a comparison to stone base courses. Since the pozzolanic base course created by the material(s) recommended in this report vary widely in compressive strength, structural layer coefficients can and have been presented in terms of strength.[13,20] The suggested coefficients are given below.

Compressive Strength	Design Layer Coefficient
< 400 psi	0.15
400 - 650 psi	0.20
650 - 1000 psi	0.30
>1000 psi	0.30 - 0.40

The allowable layer coefficient indicative of the fly ash, bottom ash and/or Donna Fill can effectively reduce the layer thickness by a half or third the required standard stone base course. However, to determine the most economical pavement section, numerous trials of alternate paving sections would have to be investigated with regard to product availability, cost, and other economical factors.

Construction Procedures

The following base course or embankment construction procedures are suggested for the recommended waste products to be used as an alternate highway construction material. Again, the alternates recommended within this report are:

100% Fly Ash

50% Fly Ash - 50% Bottom Ash

30% Fly Ash - 70% Donna Fill

The above mentioned construction alternates are hereafter collectively referred as "material(s)".

The material(s) to be used should be inspected, tested and accepted in accordance with Section 106 of the Standard Specifications for Highway Construction as adopted by the Arkansas State Highway Commission in 1978 (Standard Specifications)[12]. Report of test should include optimum moisture content, maximum dry density and 7 day compressive strength. Laboratory compaction delay must reflect the elapsed time anticipated during actual construction. The elapsed time, period between the addition of water to final compaction, must not exceed 30 minutes and should be specified as a maximum.

The roadbed should be prepared, prior to placing the base course, in accordance with Sections 210 and 212 of the Standard Specifications. Plant mixing of the material(s) is suggested, as this assures a well mixed-high quality product. Converted hot mix asphalt plants, central mix concrete plants and other "pugmill" type plants provide excellent production techniques which ensure high quality control[13]. Material placement should be with an automatic grade control paving machine capable of placing a sufficient layer of loose material either full width or half width. Sufficient material should be supplied so as not to interrupt the placing operation.

Full thickness lifts up to 8 to 10 inches, and individual lifts of at least 4 or 5 inches are generally accepted. Compaction of the base course is the most critical phase and should begin immediately behind the paving machine. Density obtained must not be less than 97 percent of the density obtained by the Materials and Research Divisions of the Arkansas State Highway and Transportation Department. Again, the required density should be achieved within 30 minutes of the addition of water to the material(s). Compaction equipment should include pneumatic tire, steel wheel and/or vibratory roller.[3, 13]

Joints must be constructed in accordance with Subsection 312.04 part (e) of the Standard Specifications. Construction joints should be provided when elapsed placement times exceed 30 minutes at adjacent partial widths[3]. Previous research has shown the base course can be overlayed as early as the next day. However, a third day core and test to verify a minimum 400 psi strength is herein suggested. If a construction or strength delay of longer than 7 days is anticipated, the base course should be sealed with a tack coat to prevent moisture loss. Construction should not be permitted when air temperatures are expected below 50^{0}F during placement and curing.

Special provisions to be used for construction and bid purposes on highway projects should include, but not be limited to, the construction and material requirements presented in the appendices. The material(s) respective appendix are:

Appendix A - Fly Ash Special Provision

Appendix B - Fly Ash/Bottom Ash Special Provision

Appendix C - Fly Ash/Donna Fill Special Provision

Area of Economical Use

The feasibility of a waste product base course is dependent on numerous construction, material, and economical factors. This makes the determination of the most economical section almost impossible. A method of bidding several equivalent pavement sections is suggested to determine the most economical section. An example of comparative base course alternates is listed below.

Bid Item	Pavement Section	
	Surface	Base
Base Bid:		
Crushed Stone Base	5"	17"
Alternate Bid:		
Fly Ash Base	3"	7"
Fly Ash/Bottom Ash Base	3"	9"
Fly Ash/Donna Fill Base	3"	9"

For the waste product alternates recommended, figures 2 and 3 realistically show areas of economical use based on current material cost and haul distances.

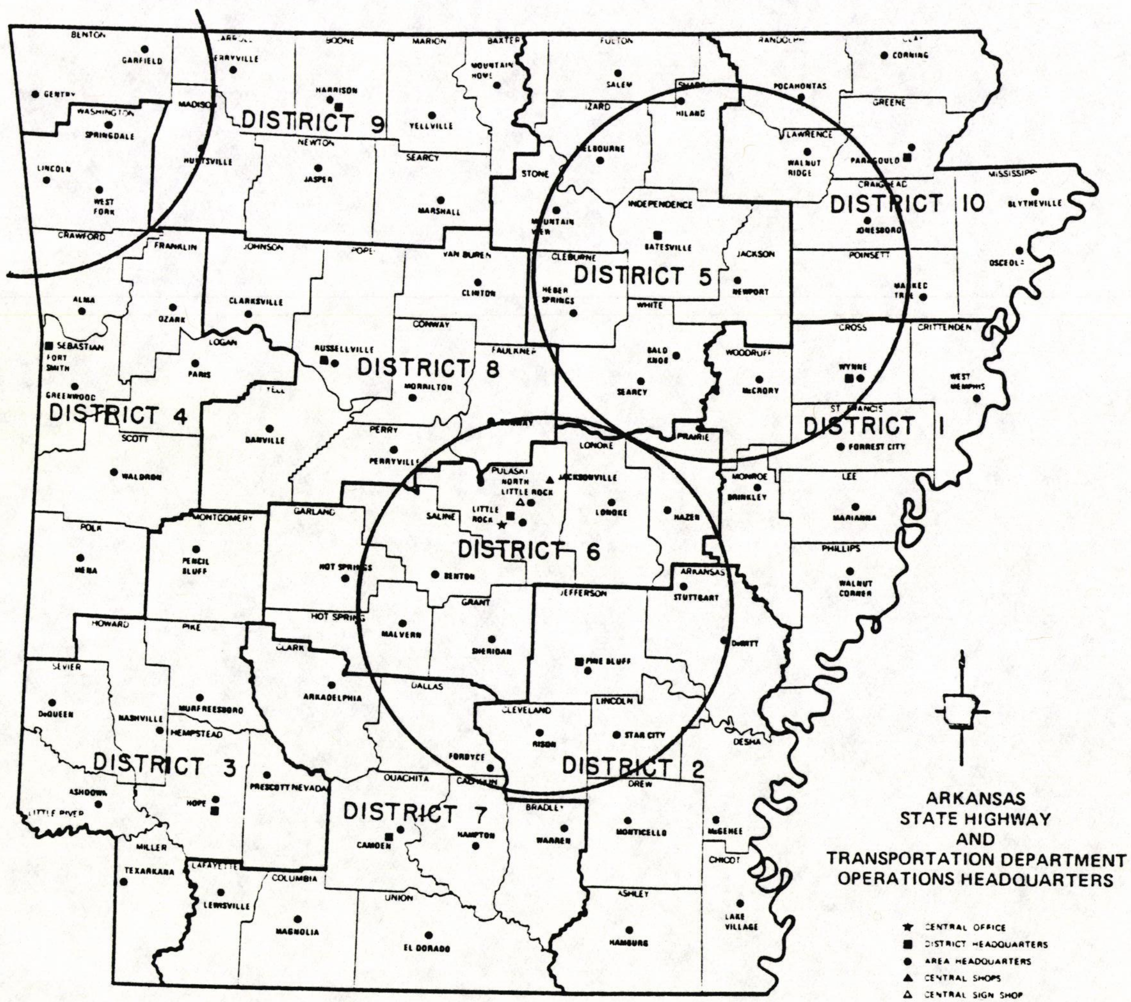

FIGURE 2. FLY ASH / BOTTOM ASH: AREA OF ECONOMICAL USE

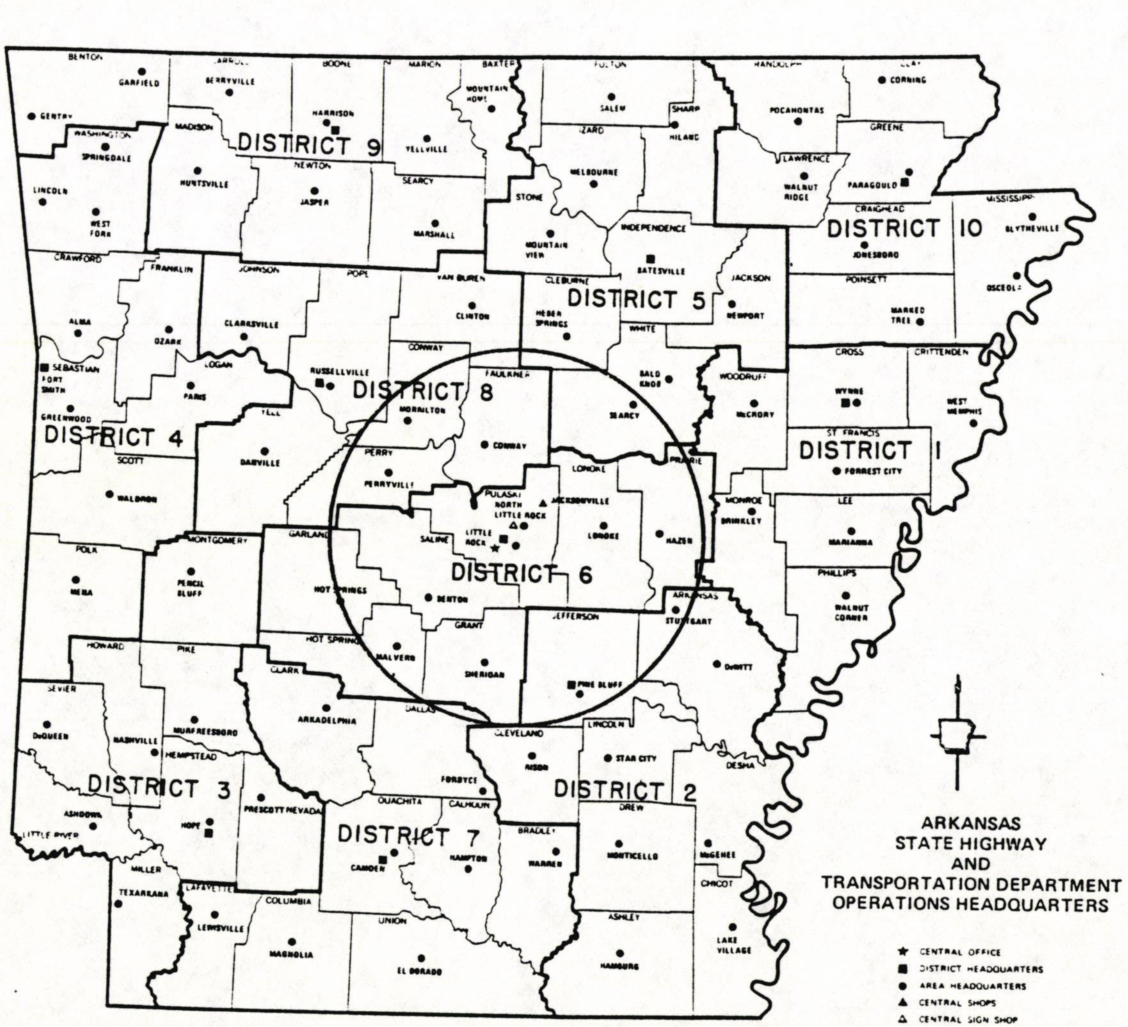

FIGURE 3. FLY ASH / DONNA FILL: AREA OF ECONOMICAL USE

Chapter Six

CONCLUSIONS

Within the limitations of the test procedures and for the materials used in this investigation, the following conclusions are made.

1. Current highway construction materials in base course and embankment construction can be replaced with waste product materials produced in Arkansas. The area of economical use is restricted by the haul distance from the source.
2. Construction material alternates, which are available in abundant quantities and have excellent laboratory performance are:

   100% Fly Ash

   50% Fly Ash - 50% Bottom Ash

   30% Fly Ash - 70% Donna Fill

   The aforementioned material(s) can be used as a construction alternate for stone course replacement with no loss to the base course integrity.

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APPENDIX A

Fly Ash Special Provision

ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT

SPECIAL PROVISION

FLY ASH BASE COURSE

DESCRIPTION: This item shall consist of a base course composed of 100 percent fly ash and water, pugmilled and constructed on an approved subgrade, in accordance with the plans, this Special Provision and applicable portions of the Standard Specifications.

MATERIALS: Fly ash and water shall meet the following applicable requirements.

Water - Water to be used shall meet the requirements of Section 312 of the Standard Specifications.

Fly Ash - The Fly ash shall meet the requirements of a Class C or Class F fly ash.

CONSTRUCTION METHODS:

(a) Preparation of the Roadbed - Prior to other construction operations, the roadbed shall be constructed in accordance with Sections 210 and 212 of the Standard Specifications.

(b) Mixing - The fly ash and water shall be mixed in a pugmill. The percentage of water used in the mix shall be as specified by the AHTD Materials and Research Engineer. Mixing shall continue until a uniform mixture of fly ash and water has been obtained.

(c) Placing Operation - The placing of the material shall be done with a paving machine that meets the approval of the Engineer and which is capable of placing a sufficient layer of loose material either full width or half width, at the option of the Contractor. The fly ash - water mixture shall be supplied in such a manner and quantity so as not to interrupt placing operation.

If 2 lifts are required to obtain the planned depth, the first lift shall be in place not less than 7 days before the second lift is begun.

If the time elapsed between the placing of adjacent partial widths exceed 30 minutes a construction joint satisfactory to the Engineer shall be provided.

(d) Compaction - The compaction shall begin immediately behind the paving machine. Either a pneumatic tired roller or a steel wheel roller that meets the approval of the Engineer shall be used.

The density obtained shall be not less than 97 percent of the density obtained by the Materials and Research Laboratory.

The surface shall not be reshaped after final compaction is complete unless directed by the Engineer.

(e) Time - The elapsed time, from the start of the addition of water to the fly ash in the pugmill until compaction is complete, shall not exceed 30 minutes.

(f) Curing - All traffic shall be excluded from each lift of the base course for a period of 7 days after compaction of the lift OR until the unconfined compressive strength as test by cores is 400 psi or greater. A prime or tack coat shall be applied if a construction delay greater than 7 days is anticipated.

(g) Joints - Joints shall be constructed in accordance with Subsection 312.04 part (e) of the Standard Specifications.

(h) Maintenance - Maintenance shall conform to Subsection 312.05 of the Standard Specifications.

(i) Temperature Limitations - Fly ash base course construction will not be permitted when the air temperature is below 50^0F.

ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT
SPECIAL PROVISION
FLY ASH BASE COURSE

METHOD OF MEASUREMENT:

(a) Fly Ash - Fly ash actually used at the direction of the Engineer will be measured by the ton dry weight in accordance with Section 109 of the Standard Specifications.

(b) Water - Water will not be measured and paid for separately, but will be considered subsidiary to the item Fly Ash Base Course.

BASIS OF PAYMENT: Work performed under this item and measured as provided above will be paid for at the contract unit price bid per ton for Fly Ash Base course, which price shall be full compensation for furnishing, transporting and placing materials; for the preparation and processing of materials; for mixing, spreading, compacting and curing; and for all labor, equipment, tools and incidentals necessary to complete the work.

Payment will be made under:

Pay Item	Pay Unit
Fly Ash Base Course	Ton

APPENDIX B

Fly Ash/Bottom Ash Special Provision

ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT
SPECIAL PROVISION
FLY ASH - BOTTOM ASH BASE COURSE

DESCRIPTION: This item shall consist of a base course composed of mixture of 50% fly ash and 50% bottom ash in accordance with the plans, this Special Provision and applicable portions of the Standard Specifications.

MATERIALS: Materials for the Fly Ash - Bottom Ash Embankment shall meet the following requirements:

Fly Ash	- Fly Ash shall meet the requirements of ASTM C 618 for Class C or F.
Bottom Ash	- Bottom Ash shall be the by-product produced by the burning of coal for power generation.
Water	- Water shall meet the requirements of Subsection 312.03 (a) of the Standard Specifications, Edition of 1978.

CONSTRUCTION METHODS:

(a) Preparation of the Roadbed - Prior to other construction operations, the roadbed shall be constructed in accordance with Sections 210 and 212 of the Standard Specifications.

(b) Mixing - The fly ash, bottom ash and water shall be mixed in a pugmill. The percentage of water used in the mix shall be as specified by the AHTD Materials and Research Engineer. Mixing shall continue until a uniform mixture of fly ash, bottom ash and water has been obtained.

(c) Placing Operation - The placing of the material shall be done with a paving machine that meets the approval of the Engineer and which is capable of placing a sufficient layer of loose material either full width or half width, at the option of the Contractor. The fly ash/bottom ash - water mixture shall be supplied in such a manner and quantity so as not to interrupt placing operation.

If 2 lifts are required to obtain the plan depth, the first lift shall be in place not less than 7 days before the second lift is begun.

If the time elapsing between the placing of adjacent partial widths exceed 30 minutes a construction joint satisfactory to the Engineer shall be provided.

(d) Compaction - The compaction shall begin immediately behind the paving machine. Either a pneumatic tired roller or a steel wheel roller that meets the approval of the Engineer shall be used.

The density obtained shall be not less than 97 percent of the density obtained by the Materials and Research Laboratory.

The surface shall not be reshaped after final compaction is complete unless directed by the Engineer.

(e) Time - The elapsed time, from the start of the addition of water to the fly ash/bottom ash in the pugmill until compaction is complete, shall not exceed 30 minutes.

(f) Curing - All traffic shall be excluded from each lift of the base course for a period of 7 days after compaction of the lift OR until the unconfined compressive strength as test by cores is 400 psi or greater. A prime or tack coat shall be applied if a construction delay greater than 7 days is anticipated.

(g) Joints - Joints shall be constructed in accordance with Subsection 312.04 part (e) of the Standard Specifications.

(h) Maintenance - Maintenance shall conform to Subsection 312.05 of the Standard Specifications.

SEASONAL AND TEMPERATURE LIMITATIONS: Fly Ash-Bottom Ash embankment construction will not be permitted when the air temperature is below 50^{o}F. nor will it be permitted between November 30 and April 1 unless written approval is given by the Engineer.

METHOD OF MEASUREMENT: Fly Ash-Bottom Ash embankment completed in place shall be measured by the ton in accordance with Section 109 of the Standard Specifications.

ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT
SPECIAL PROVISION
FLY ASH-BOTTOM ASH BASE COURSE

BASIS OF PAYMENT: Work performed and accepted under this item and measured as provided above will be paid for at the contract unit price bid per ton for Fly Ash-Bottom Ash, which price shall be full compensation for furnishing, hauling, and placing all materials; for mixing, watering, compacting and finishing the embankment; and for all labor, tools and incidentals necessary to complete the work.

Payment will be made under:

Pay Item	Pay Unit
Fly Ash-Bottom Ash	Ton

APPENDIX C

Fly Ash/Donna Fill Special Provision

ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT
SPECIAL PROVISION
FLY ASH/DONNA FILL BASE COURSE

DESCRIPTION: This item shall consist of a base course composed of a mixture of 70% Donna Fill and 30% Fly Ash constructed in accordance with the plans, this Special Provision and applicable portions of the Standard Specifications.

MATERIALS: Materials for the Fly Ash/Donna Fill Embankment shall meet the following requirements:

Donna Fill - This item shall be nepheline syenite granite, a by-product of crushing syenite granite rock. The material furnished shall be free from sod, stumps, logs, roots, or other perishable or deleterious matter.

Fly Ash - The Fly Ash shall meet the requirements of a Class C or Class F Fly Ash.

Water - Water shall meet the requirements of subsection 312.03 (a) of the Standard Specifications, Edition of 1978.

CONSTRUCTION METHODS

(a) Preparation of the Roadbed - Prior to other construction operations, the roadbed shall be constructed in accordance with Sections 210 and 212 of the Standard Specifications.

(b) Mixing - The fly ash, Donna Fill and water shall be mixed in a pugmill. The percentage of water used in the mix shall be as specified by the AHTD Materials and Research Engineer. Mixing shall continue until a uniform mixture of fly ashy, Donna Fill and water has been obtained.

(c) Placing Operation - The placing of the material shall be done with a paving machine that meets the approval of the Engineer and which is capable of placing a sufficient layer of loose material either full width or half width, at the option of the Contractor. The Fly Ash/Donna Fill - water mixture shall be supplied in such a manner and quantity so as not to interrupt placing operation.

If 2 lifts are required to obtain the plan depth, the first lift shall be in place not less than 7 days before the second lift is begun.

If the time elapsing between the placing of adjacent partial widths exceed 30 minutes a construction joint satisfactory to the Engineer shall be provided.

(d) Compaction - The compaction shall begin immediately behind the paving machine. Either a pneumatic tired roller or a steel wheel roller that meets the approval of the Engineer shall be used.

The density obtained shall be not less than 97 percent of the density obtained by the Materials and Research Laboratory.

The surface shall not be reshaped after final compaction is complete unless directed by the Engineer.

(e) Time - The elapsed time, from the start of the addition of water to the Fly Ash/Donna Fill in the pugmill until compaction is complete, shall not exceed 30 minutes.

(f) Curing - All traffic shall be excluded from each lift of the base course for a period of 7 days after compaction of the lift OR until the unconfined compressive strength as test by cores is 400 psi or greater. A prime or tack coat shall be applied if a construction delay greater than 7 days is anticipated.

(g) Joints - Joints shall be constructed in accordance with Subsection 312.04 part (e) of the Standard Specifications.

(h) Maintenance - Maintenance shall conform to Subsection 312.05 of the Standard Specifications.

(i) Temperature Limitations - Fly Ash/Donna Fill base course construction will not be permitted when the air temperature is below 50 ^{0}F.

METHOD OF MEASUREMENT:

Donna Fill completed in place will be measured by the ton in accordance with Section 109 of the Standard Specifications.

Fly Ash completed in place will be measured by the ton in accordance with Section 109 of the Standard Specifications.

ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT
SPECIAL PROVISIONS
FLY ASH/DONNA FILL BASE COURSE

BASIS OF PAYMENT: Work performed and accepted under this item will be paid for as follows:

A. Donna Fill, measured as provided above, will be paid for at the contract unit price bid per ton for Donna Fill in accordance with Section 109 of the Standard Specifications.

B. Fly Ash, measured as provided above, will be paid for at the contract unit price bid per ton for Fly Ash in accordance with Section 109 of the Standard Specifications.

C. Water - Water will not be measured and paid for separately, but will be considered subsidiary to the item Fly Ash/Donna Fill Embankment.

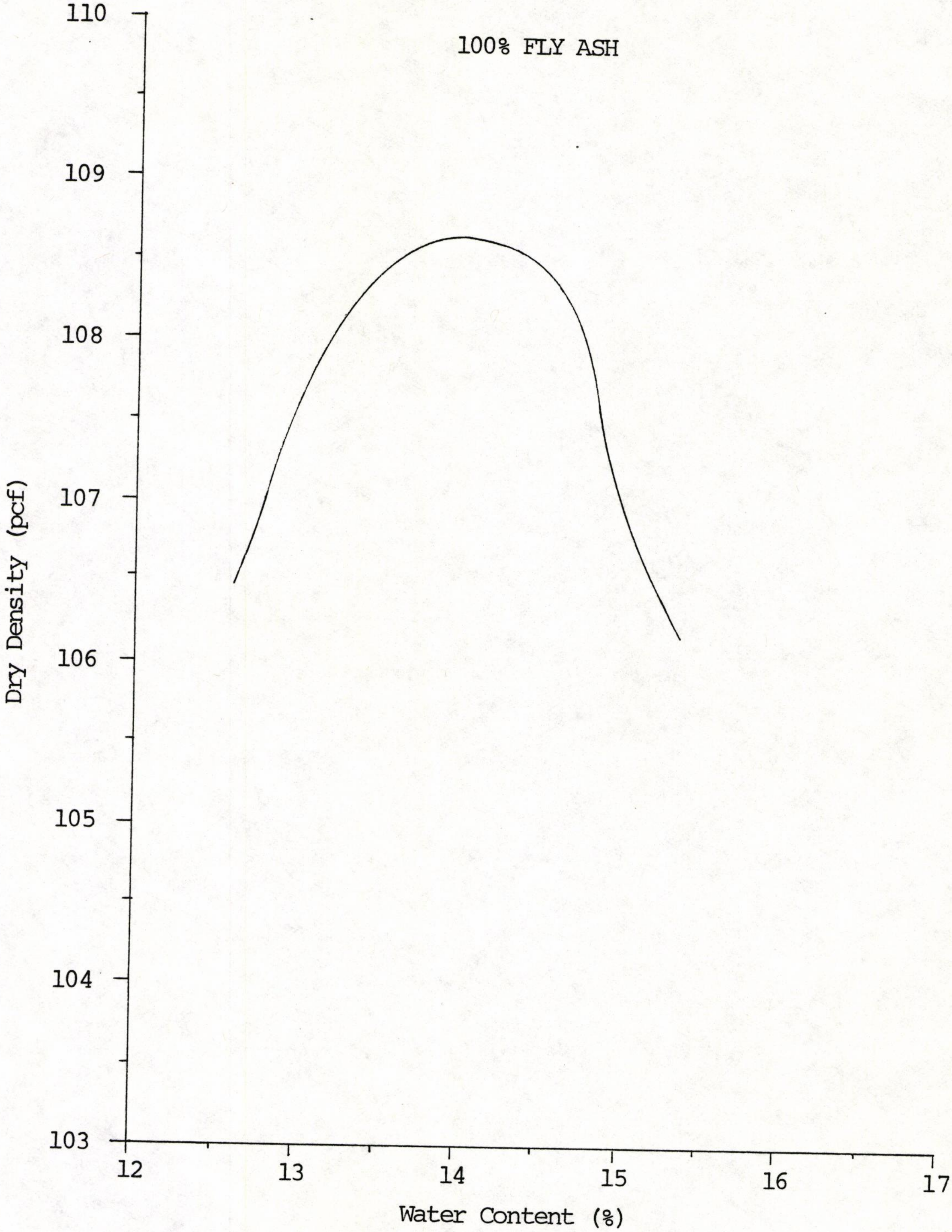
The contract unit prices mentioned above shall be full compensation for furnishing, hauling and placing all materials; for mixing, watering, compacting and finishing the embankment; and for all labor, tools, equipment and incidentals necessary to complete the work.

Payment will be made under:

Pay Item	Pay Unit
Donna Fill	Ton
Fly Ash	Ton

APPENDIX D

Moisture/Density Relationships



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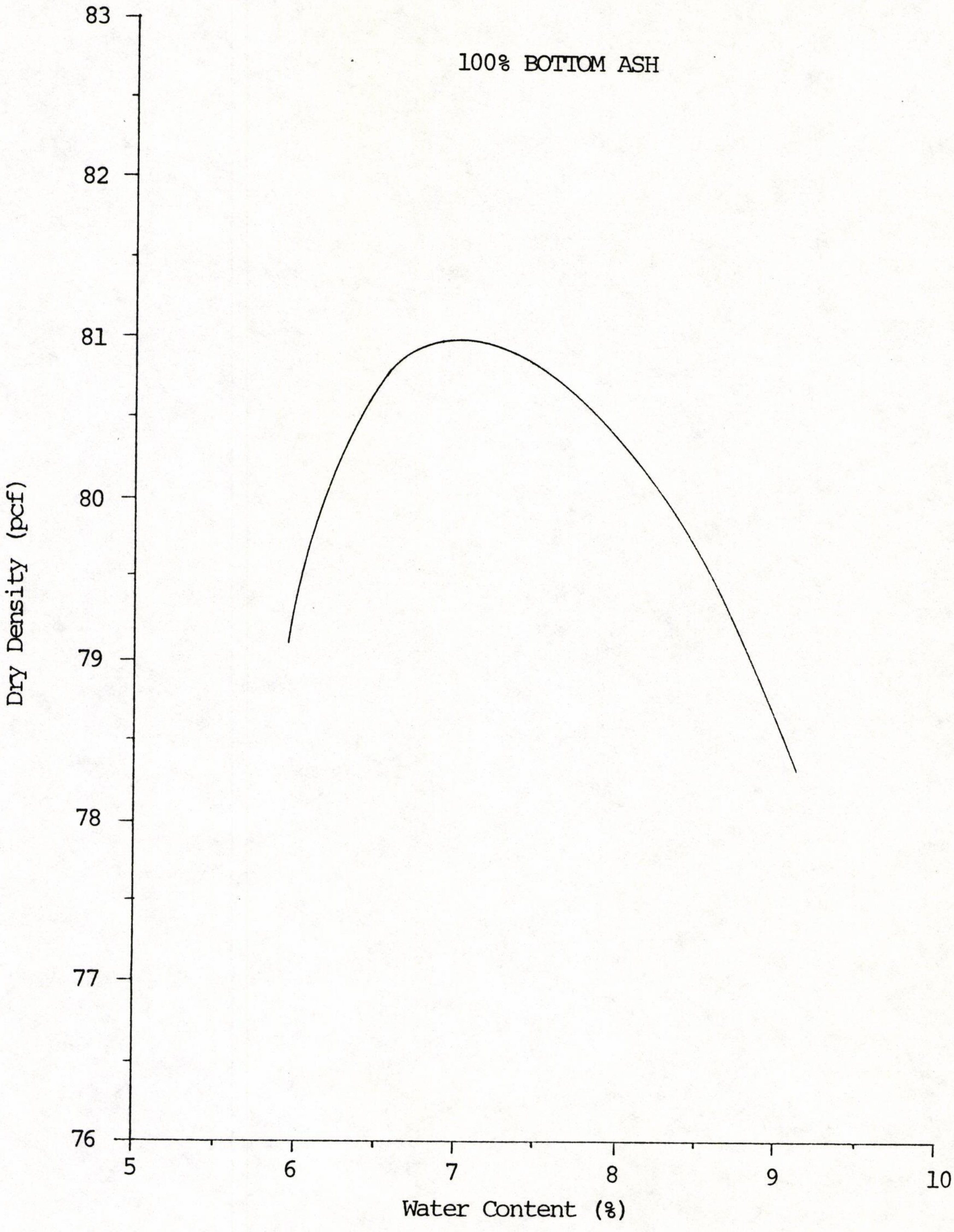

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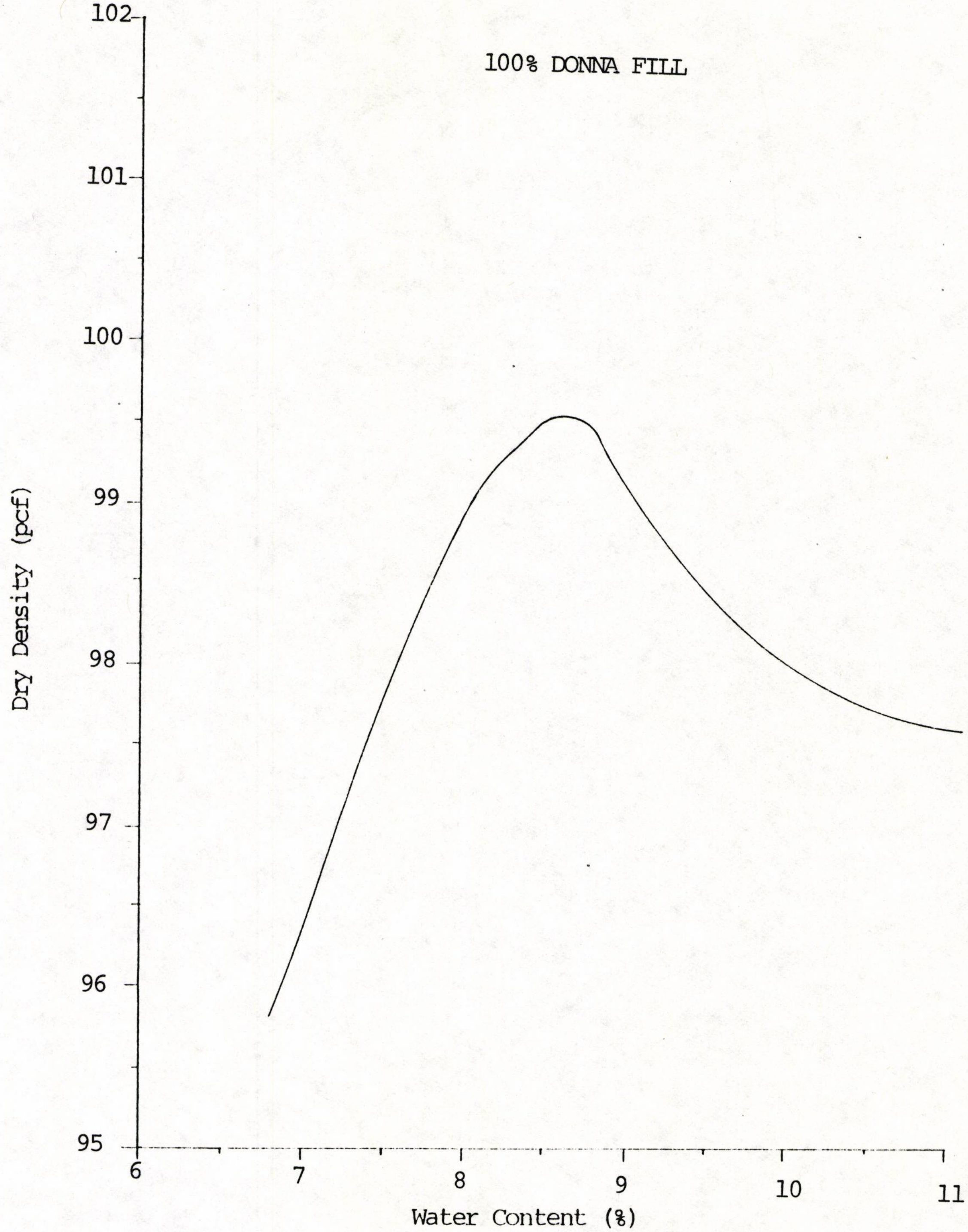

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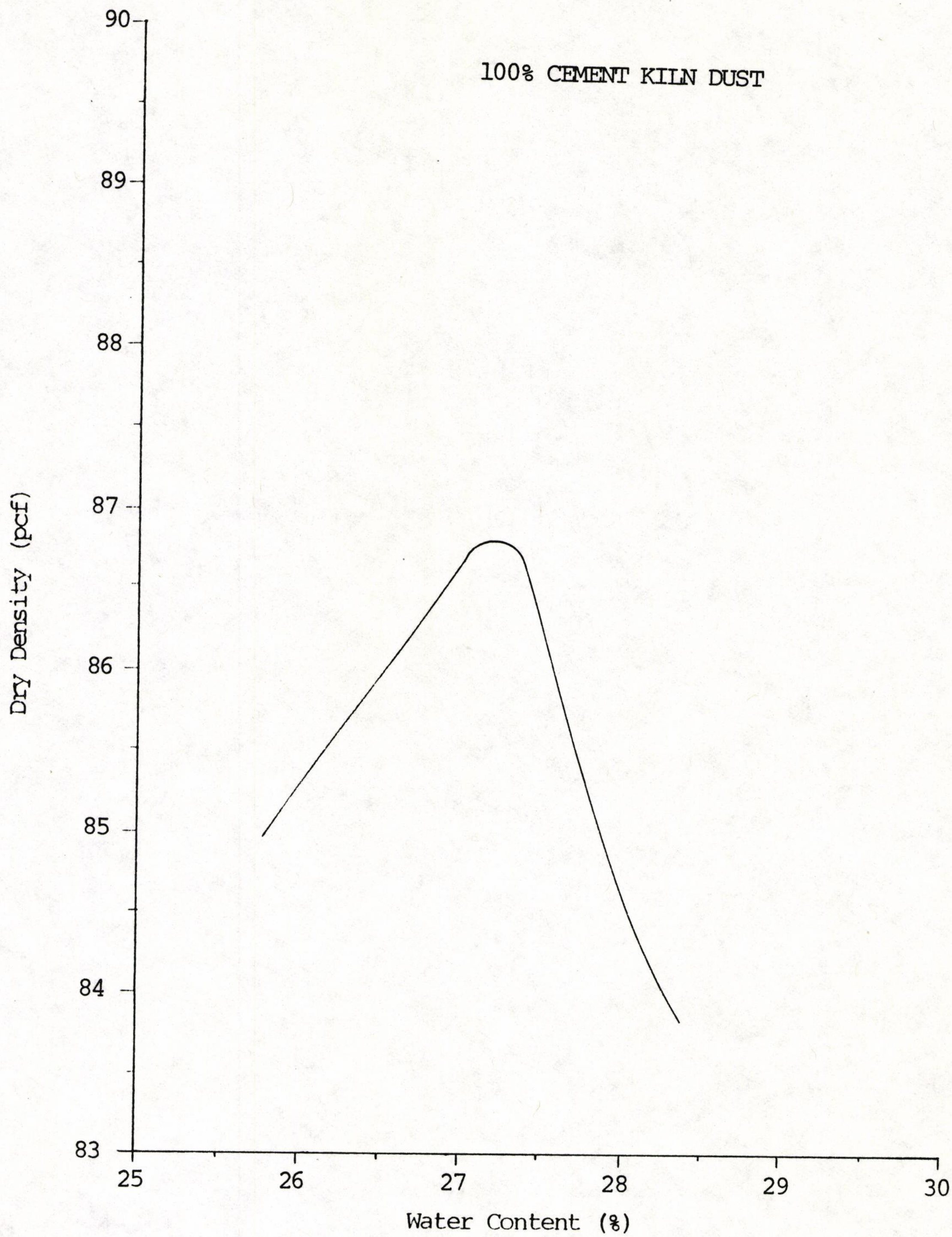

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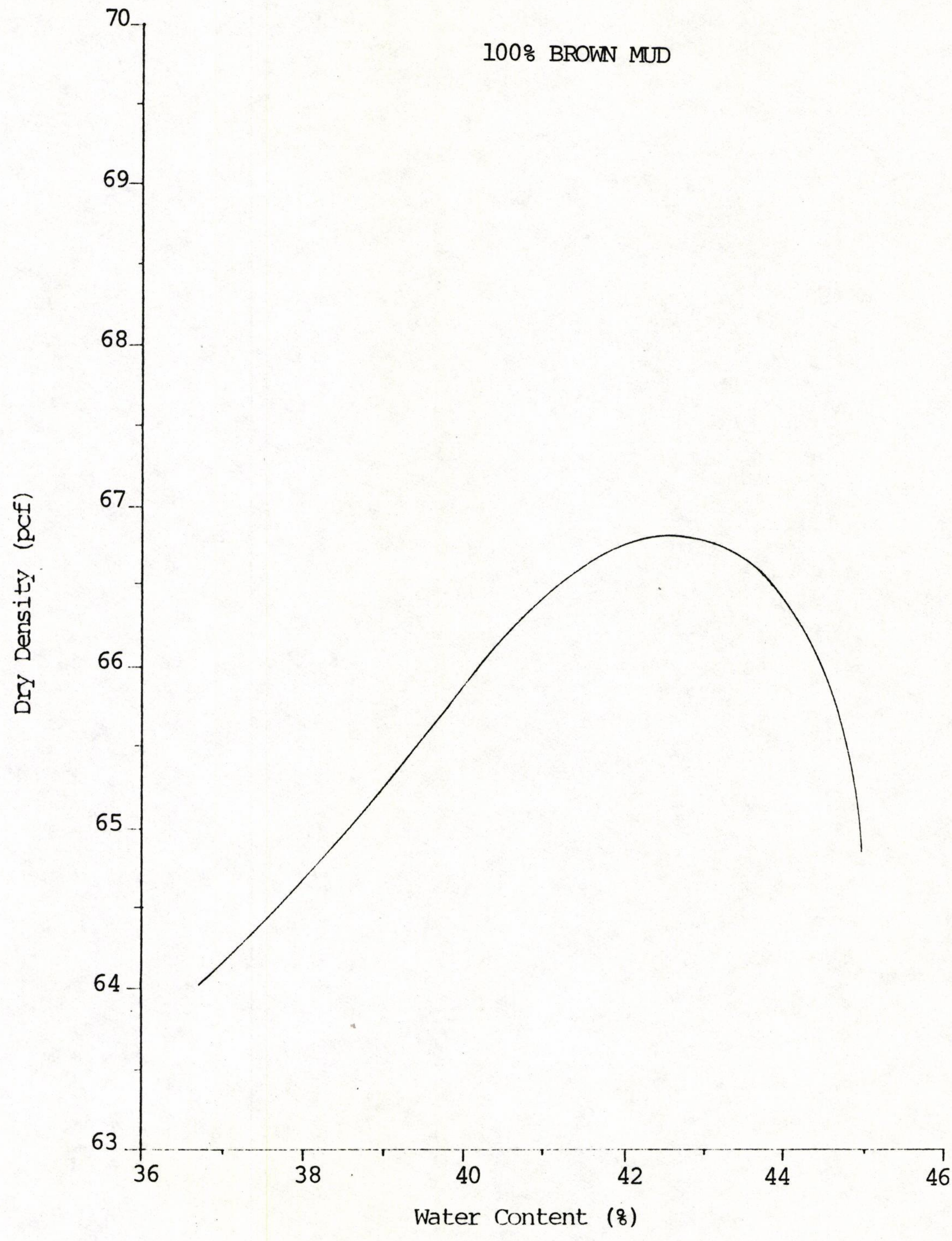

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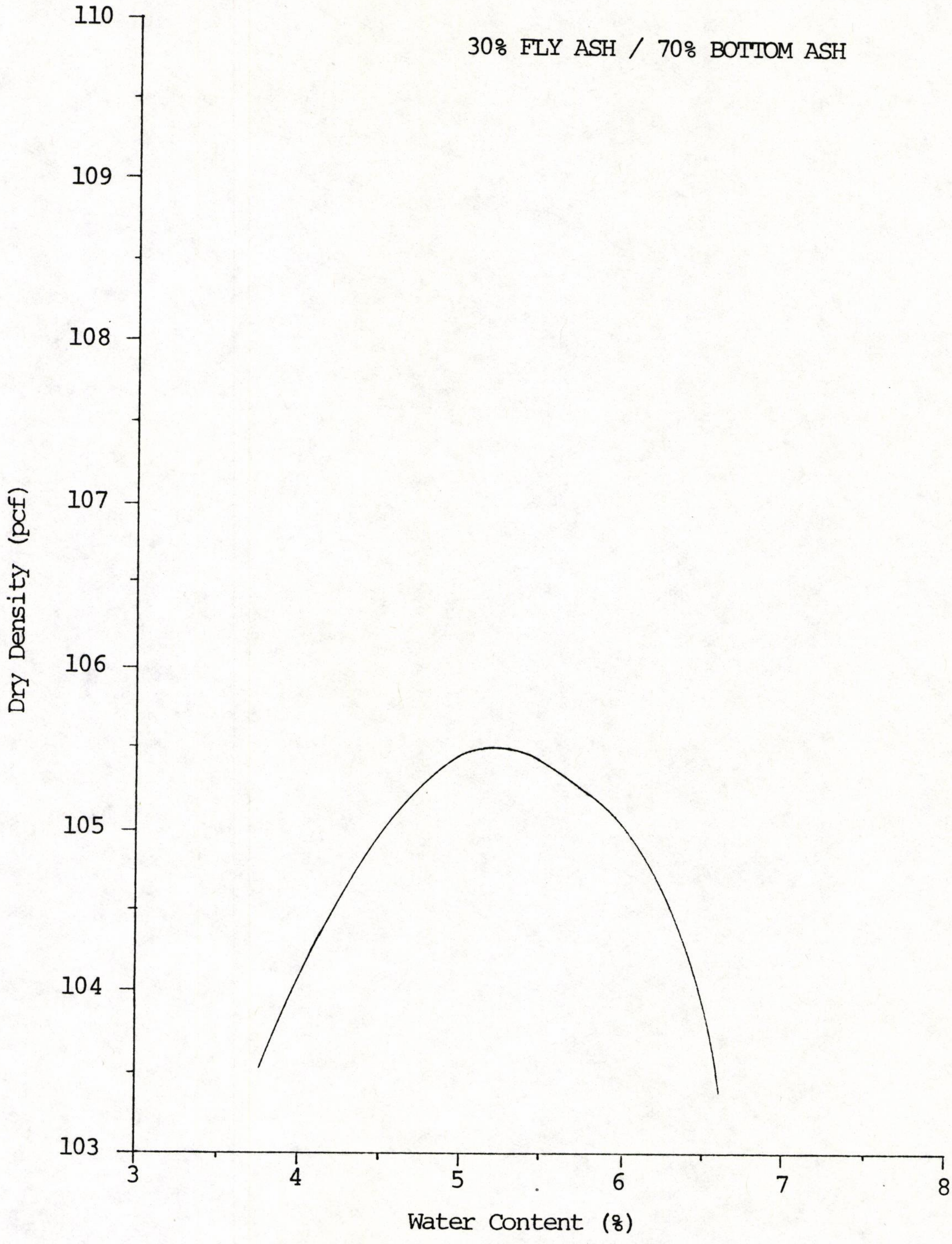

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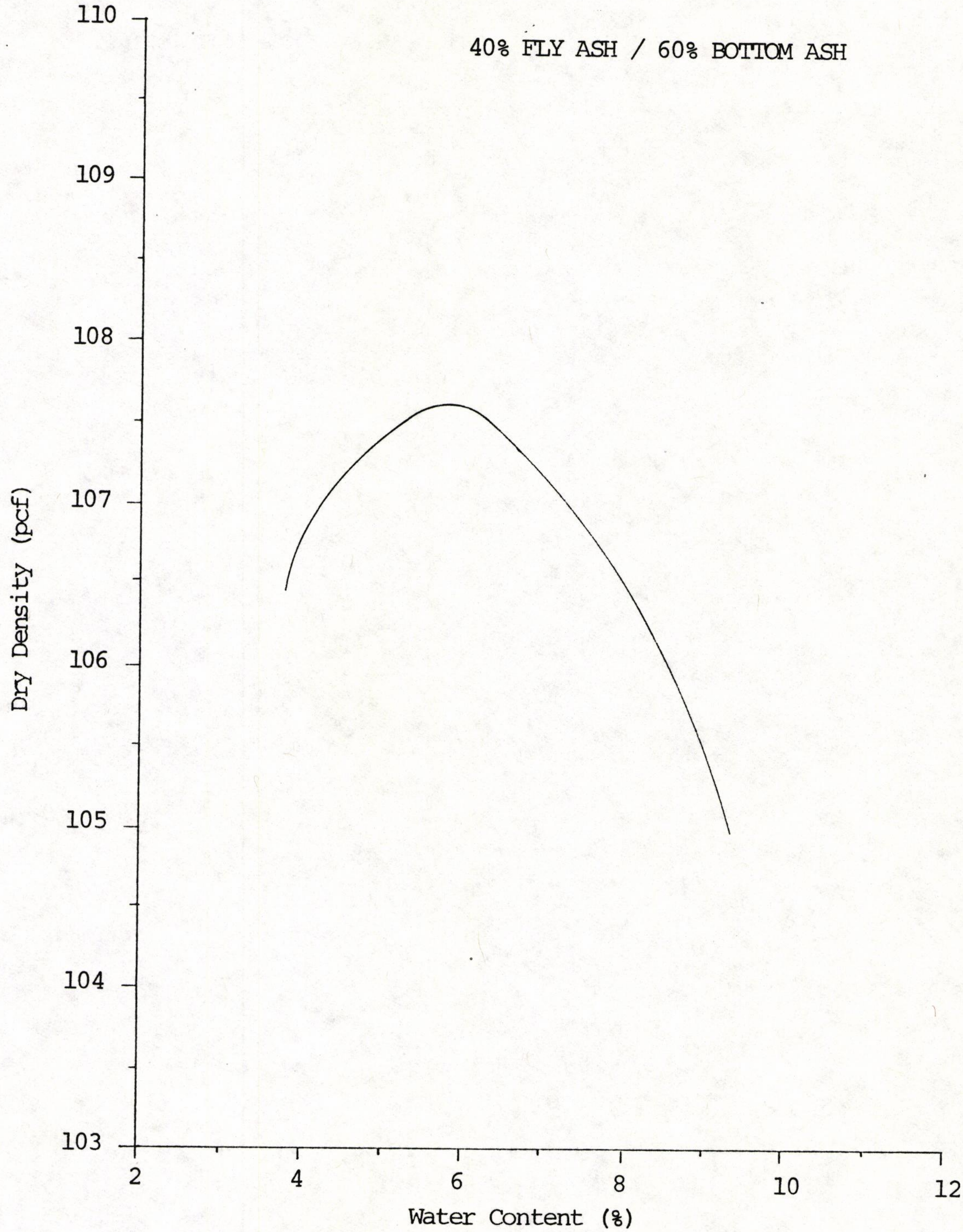

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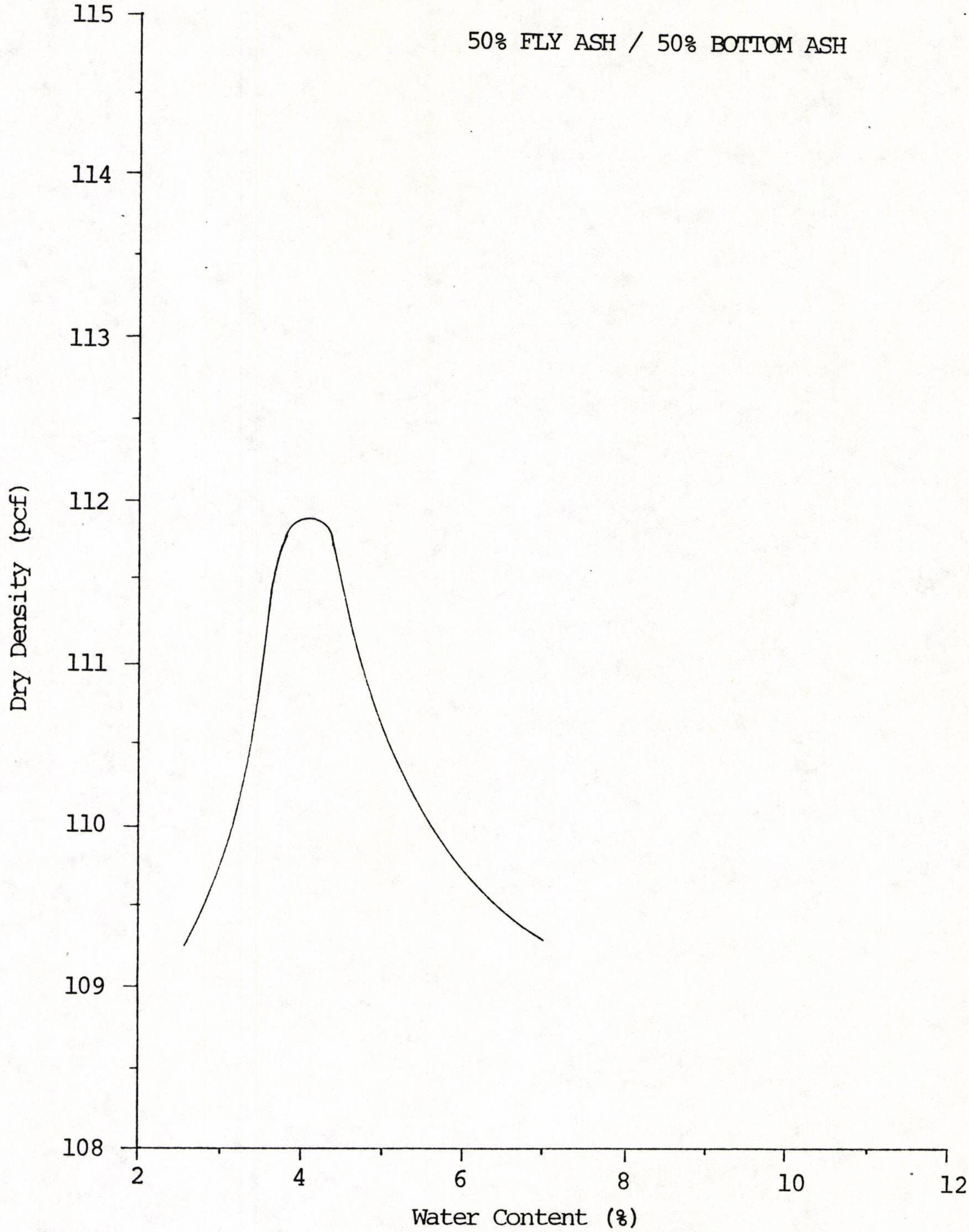

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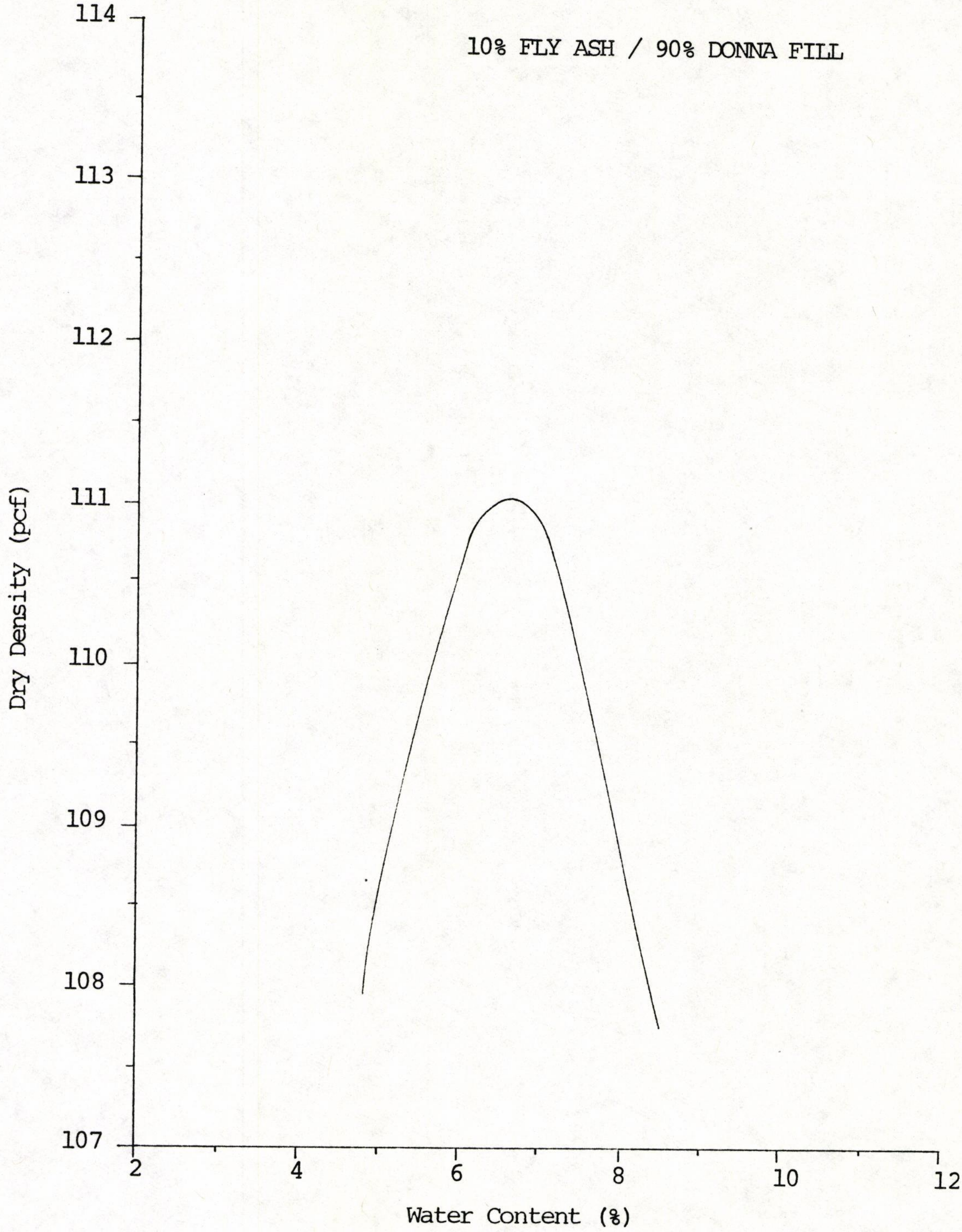

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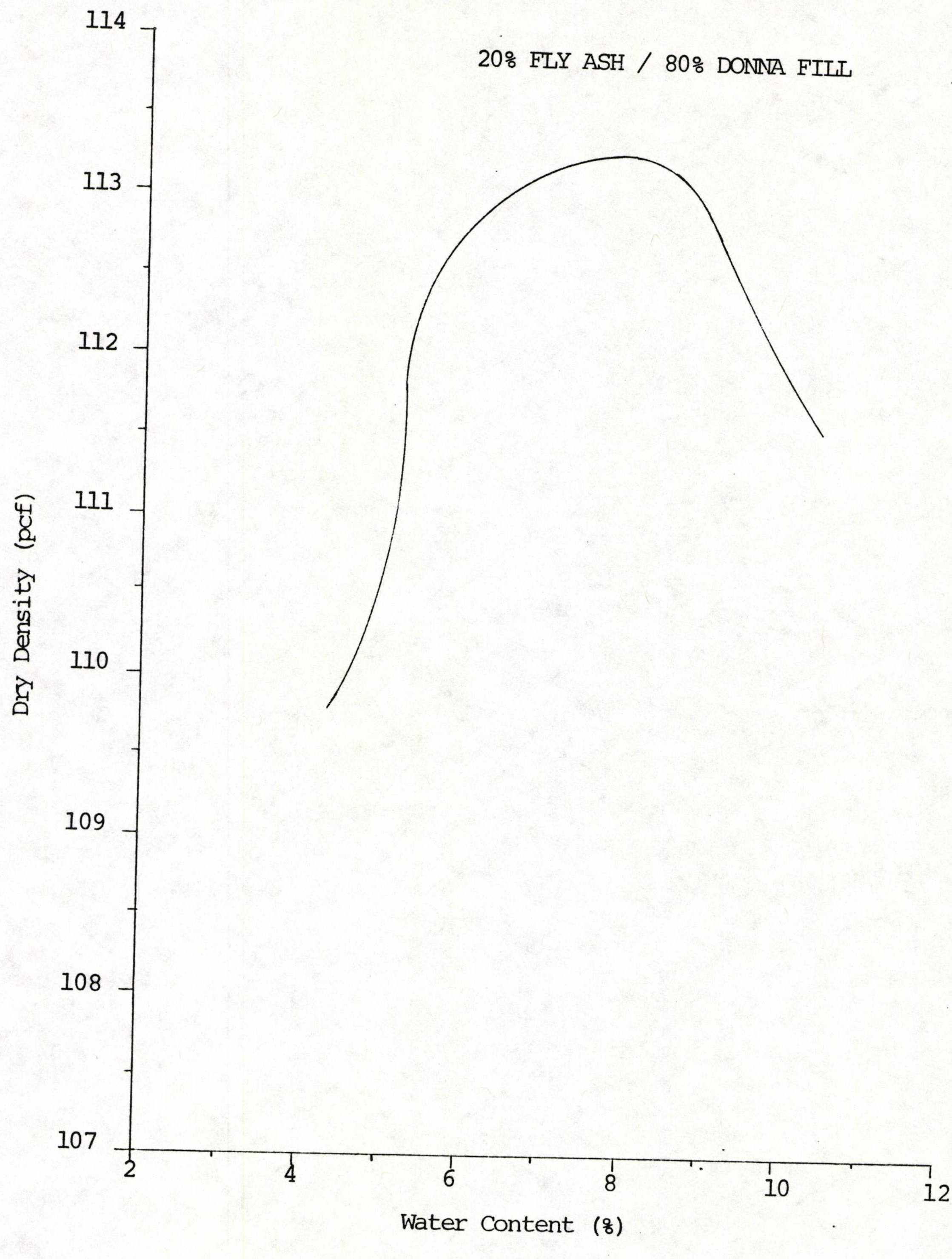

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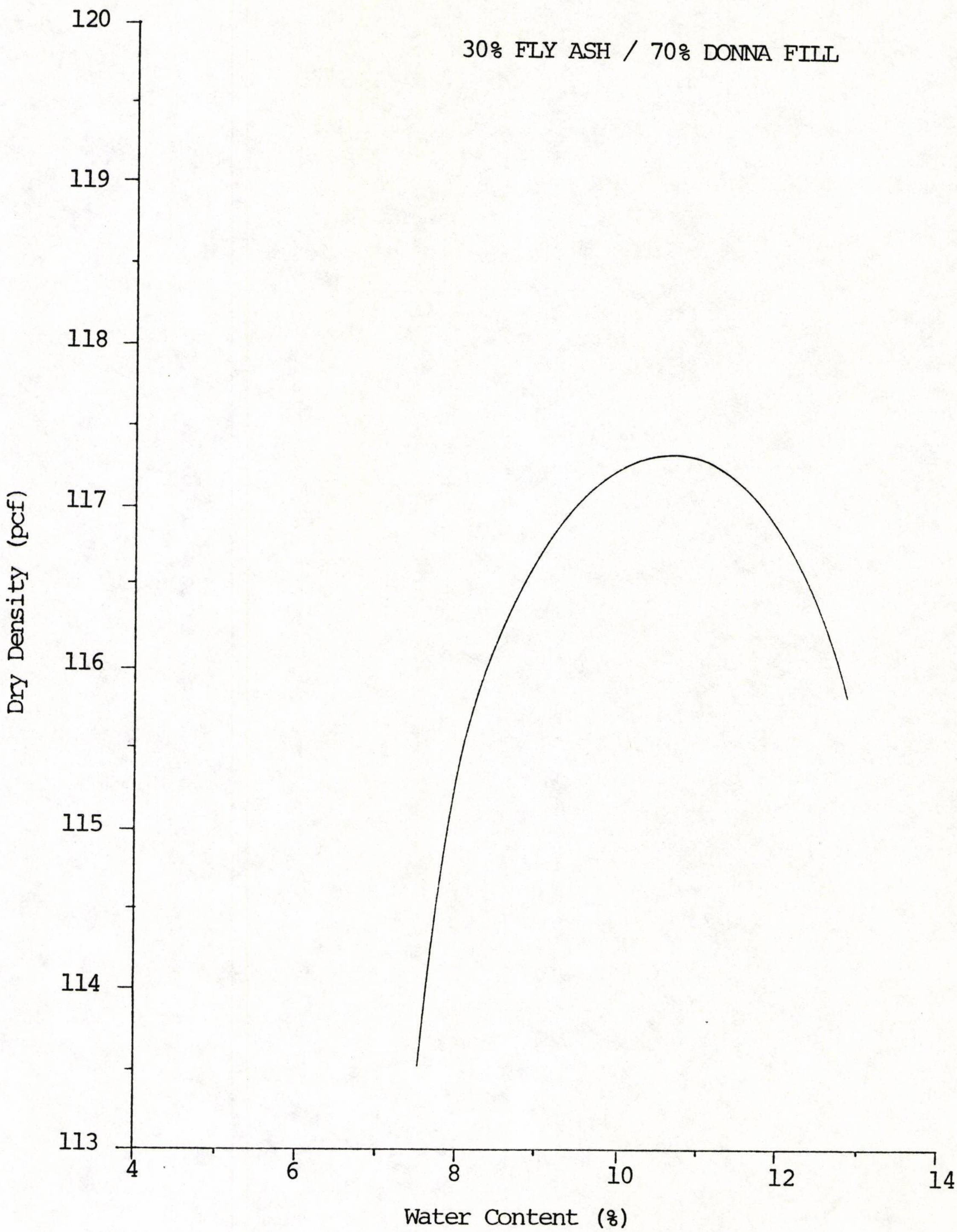

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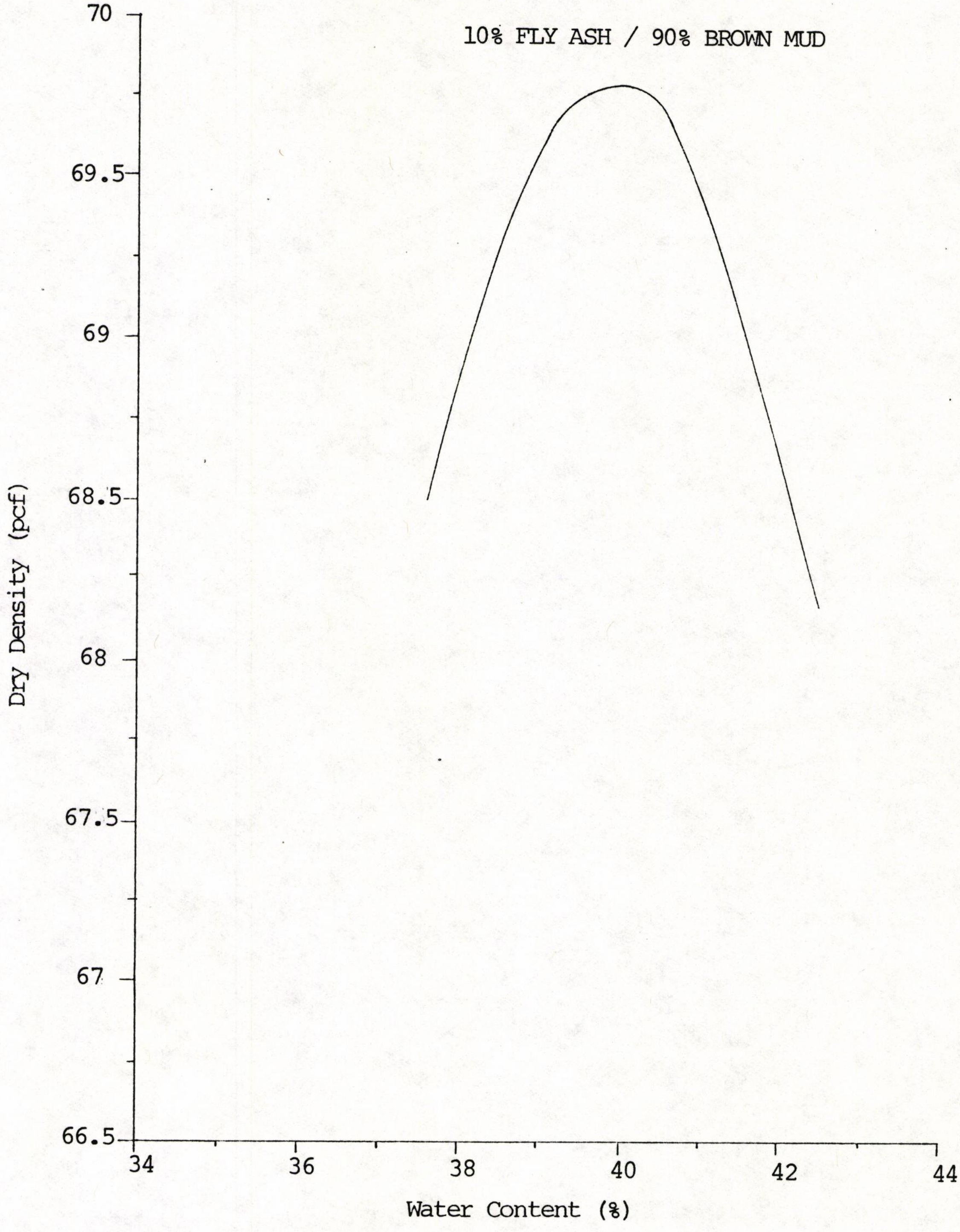

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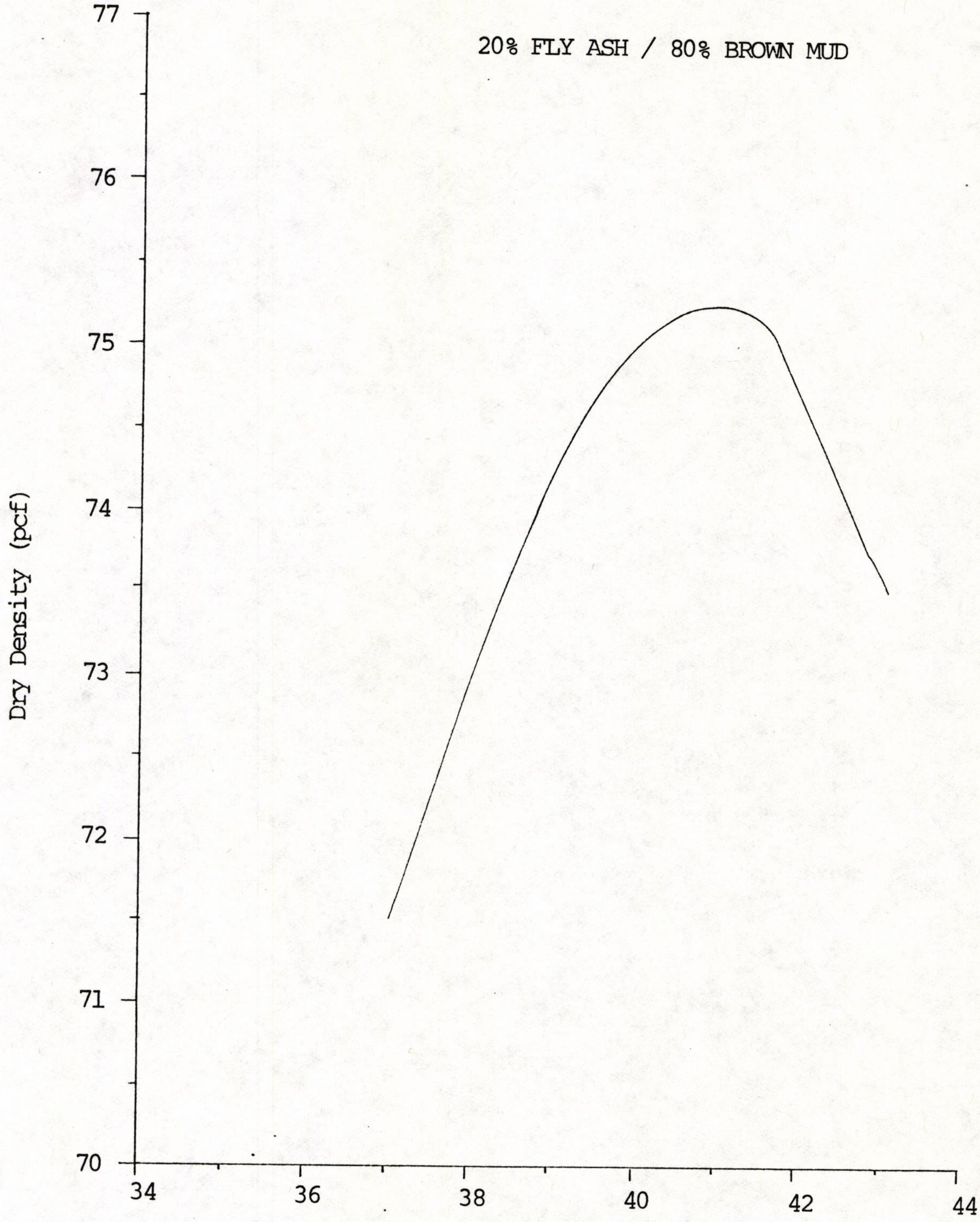

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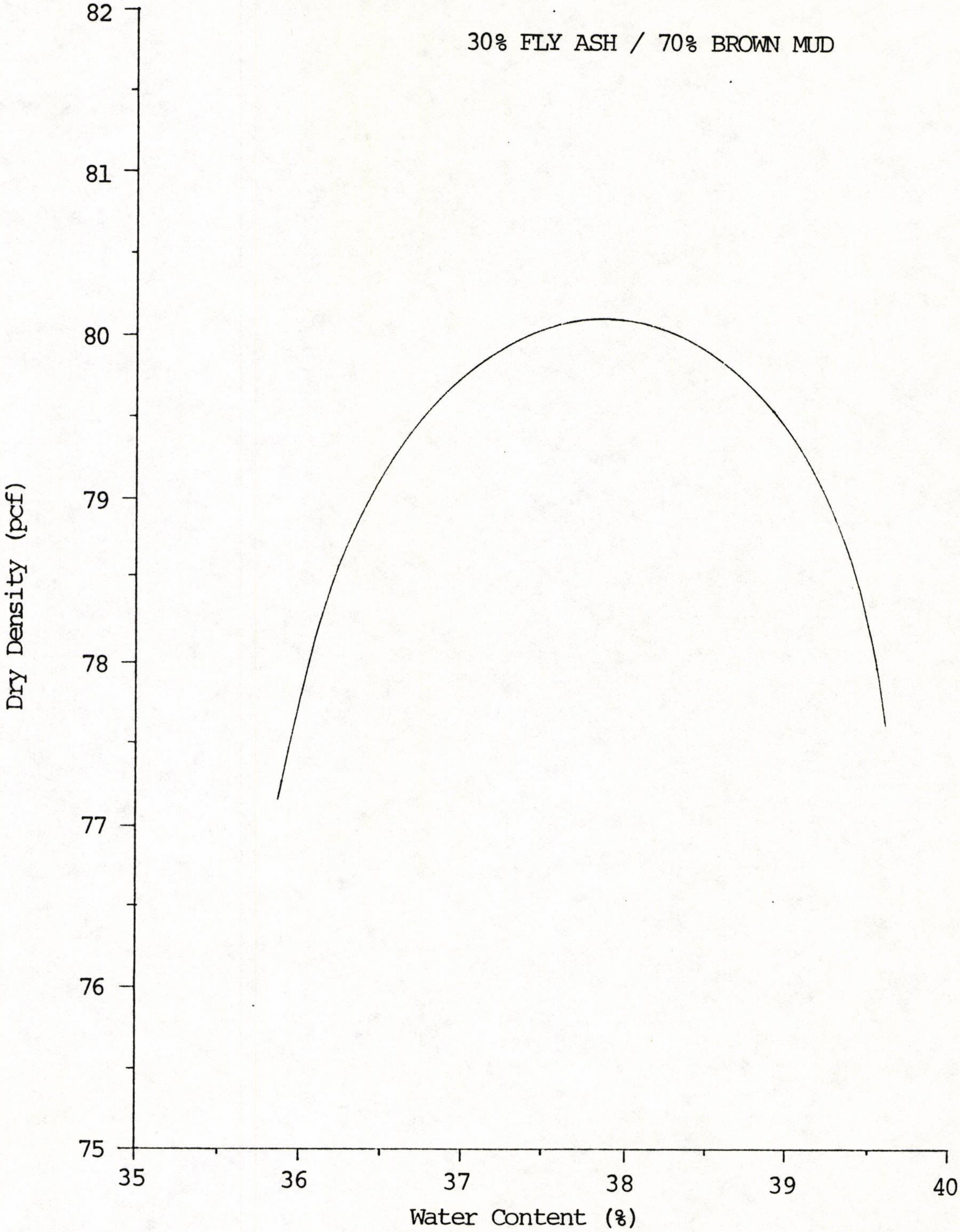

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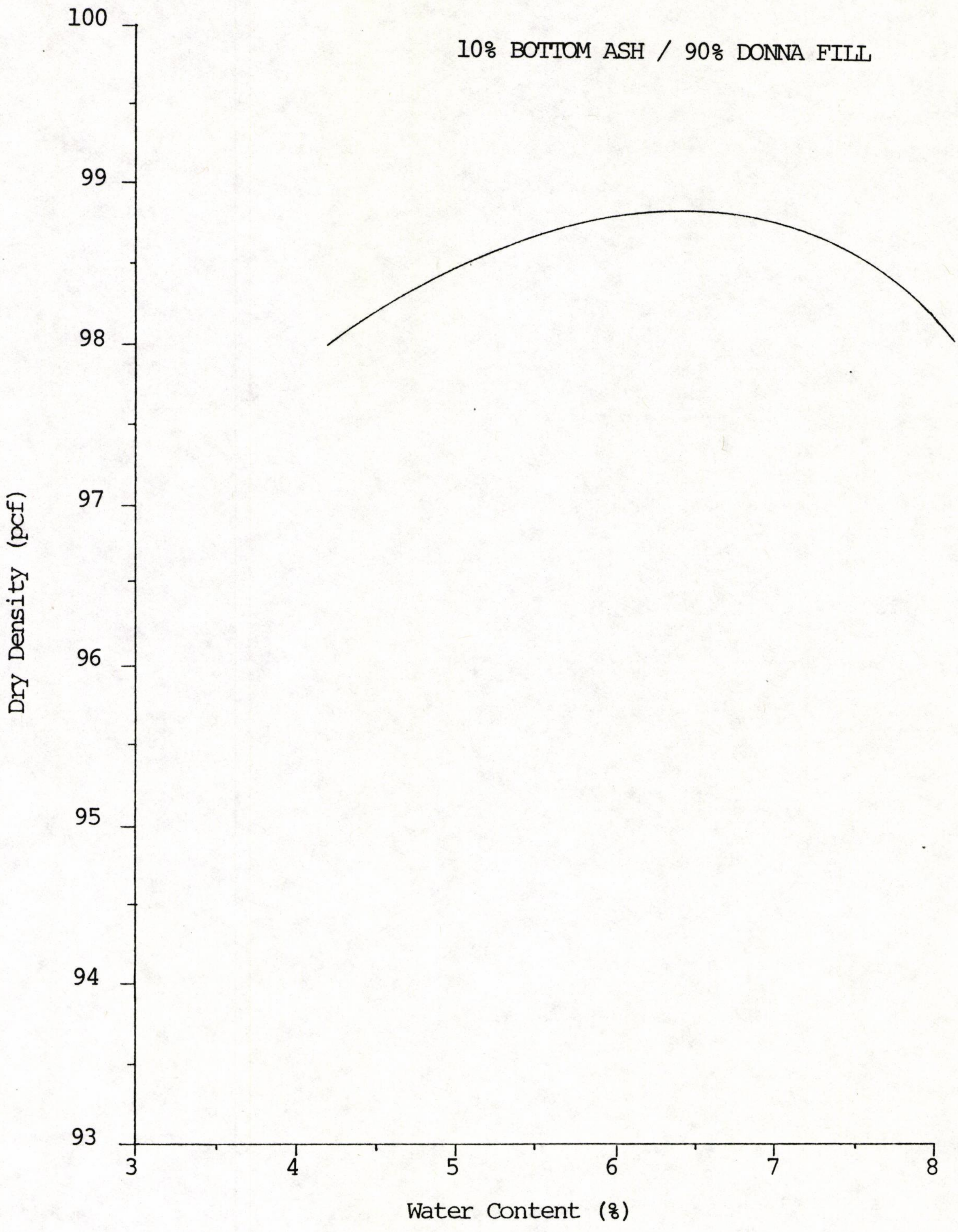

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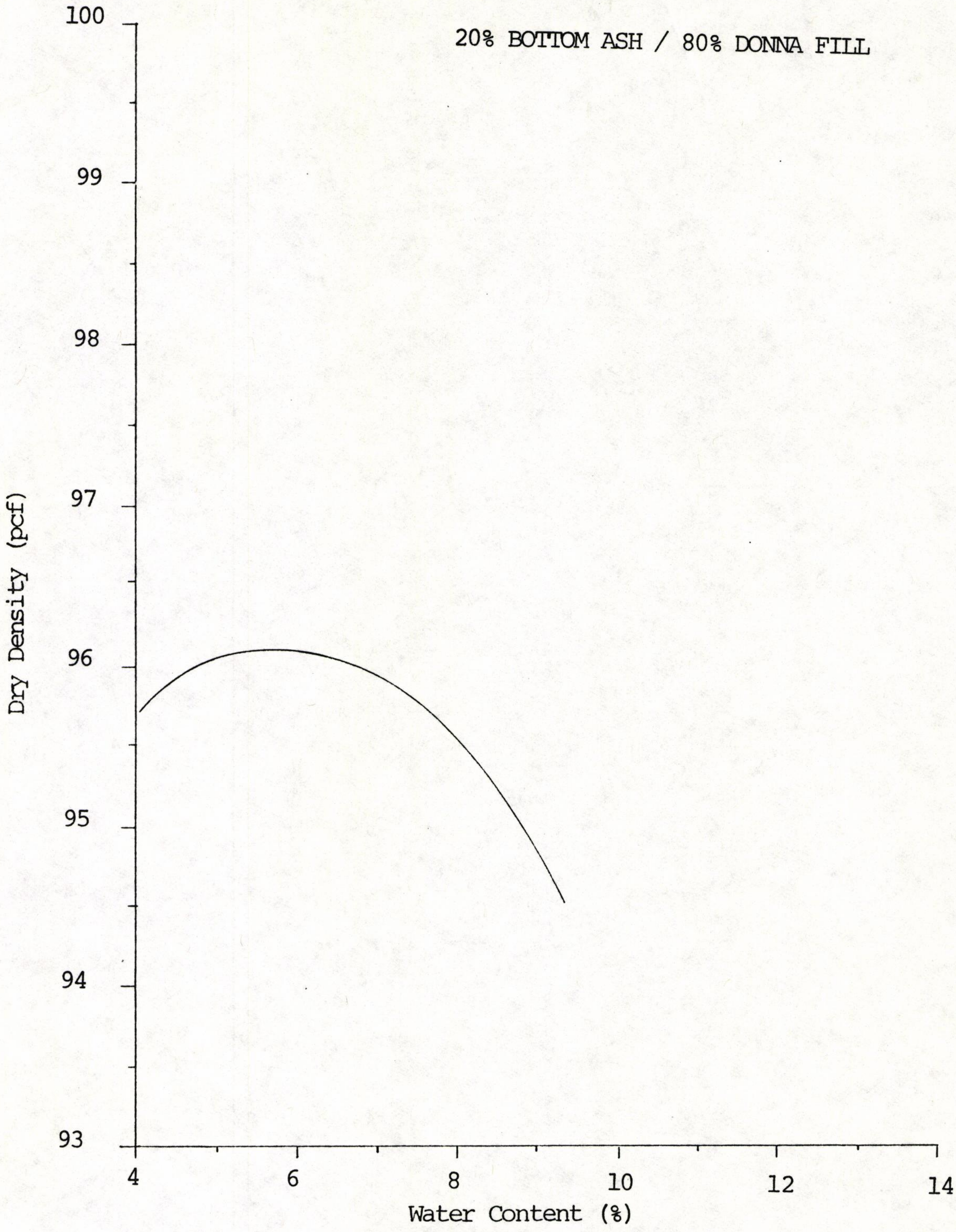

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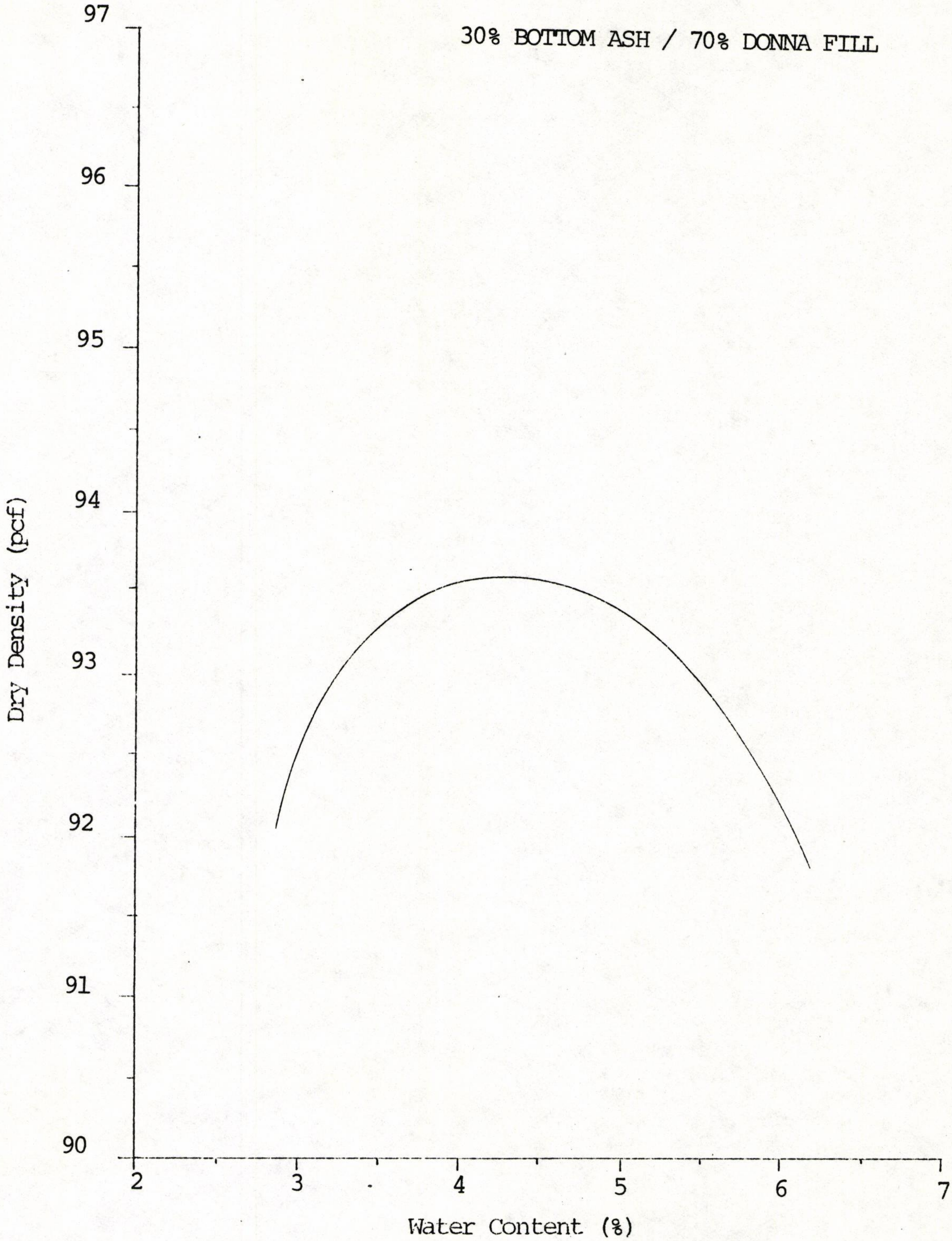

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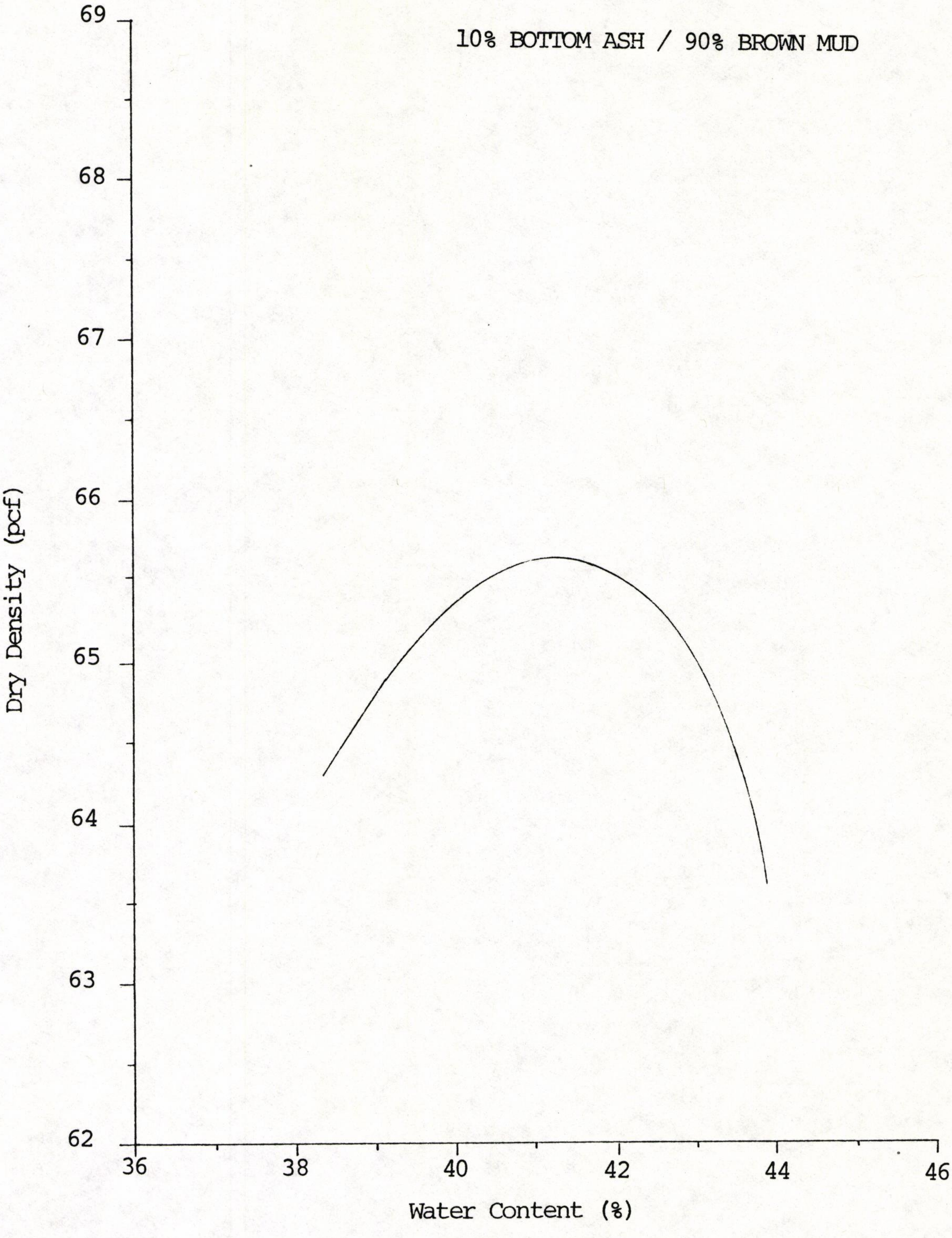

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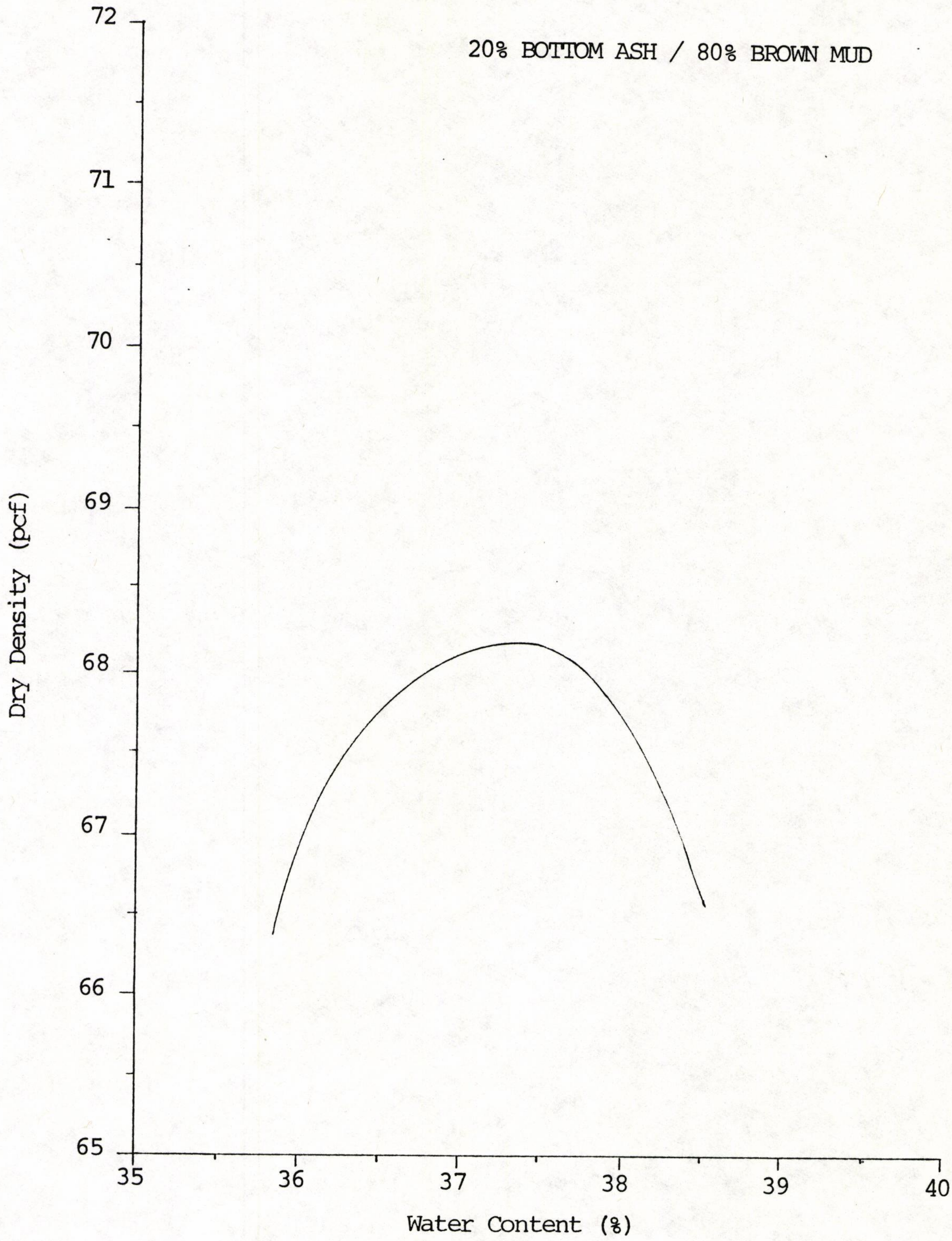

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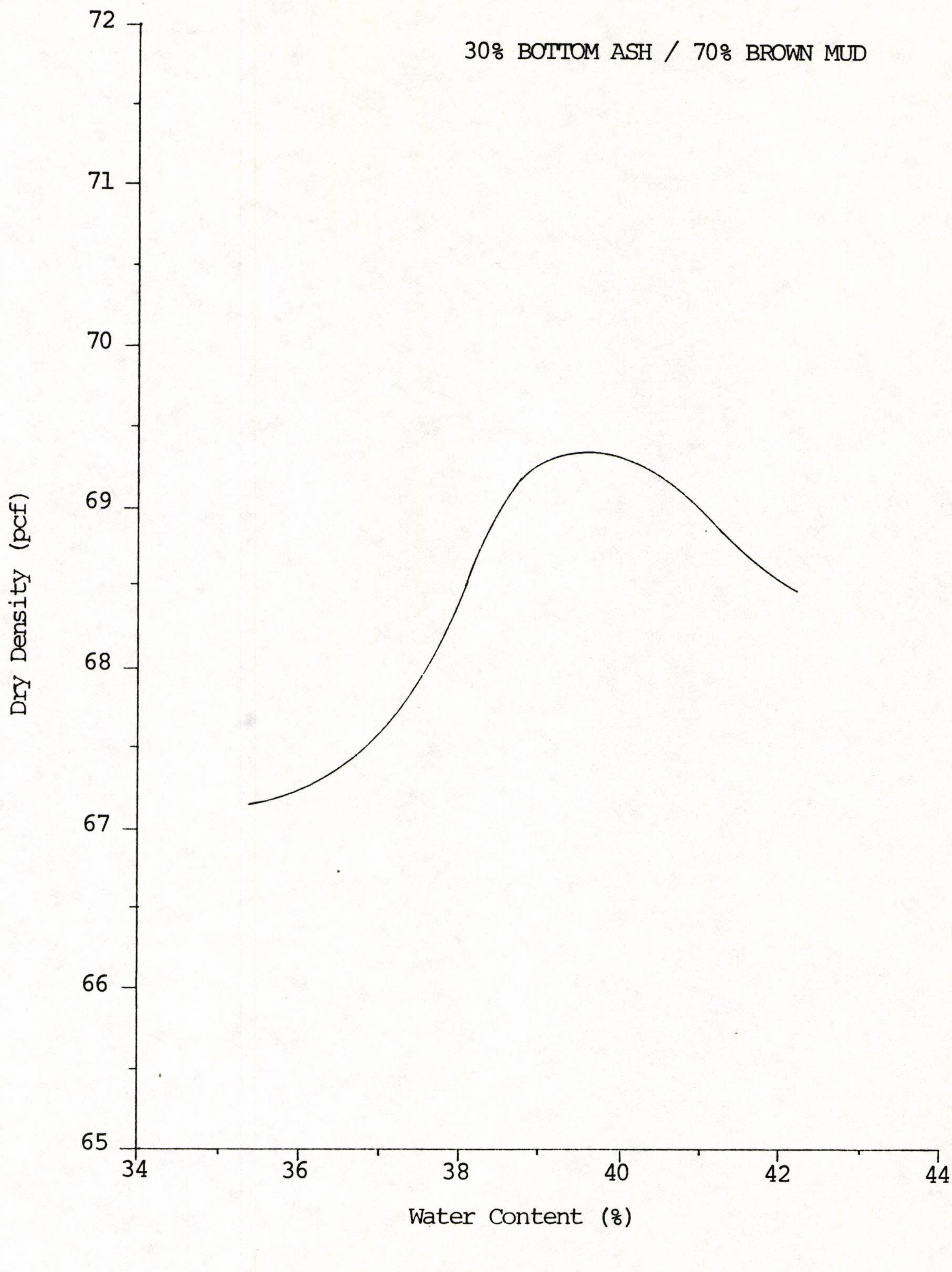

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