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MASTIC ASPHALT FOR MAINTENANCE

by

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ABSTRACT

This work was concerned with mix design and evaluation of mastic asphalt for pavement maintenance. A special mixer was designed and built for this purpose. Asphalt, gravel, sand and filler (Fly Ash) were mixed hot for times ranging between 1 to 5 hours. A Latin Squares statistical design was chosen to include all variables using minimum number of specimens. The mixes were evaluated using selected tests to assess the projected performance of each mix. Marshall properties and resilient modulus were measured. Selected specimens were tested for moisture and freeze-thaw damage. Different mixture compositions are recommended for different pothole and crack sizes.

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DISCLAIMER

INTRODUCTION

One of the problems that face highway departments in the United States is holes and cracks in pavement surfaces. Many attempts are being made to find a way for permanent repairs. This may be best done by controlling the quality of the patching material, hole preparation, and general repair workmanship.

Cavities in bituminous and portland cement pavements vary in sizes and shapes depending on the local conditions and time. In a mature stage, the depth of a hole may be the same as the thickness of the surface course or deeper.

The cause of potholes and other cavities in bituminous pavements is generally attributed to the localized weaknesses of the pavement due to one or more of the following:

- too much or too little fines in the mix
- too little binder
- inadequate compaction
- the presence of unsuitable aggregate and/or deleterious substances in the mix.

In portland cement concrete pavements various types and shapes of cavities may develop at joints, cracks, and other areas of the slabs. These defects can be often attributed to deficiencies in materials and workmanship.

From the above it is clear that a potential for a hole can be built in during the production and construction of a pavement. These cavities are then induced by variable weather conditions (freeze thaw cycles and large changes in temperature), due to cyclic load by heavy traffic, and other factors.

In order to tackle the problem of holes, the following questions could be asked:

- how can holes be economically repaired?
- what is the best mixture to be used?
- what are the necessary equipment and methods required?
- how can we minimize traffic interference?

To answer the above questions one would start to think about certain goals that need to be achieved. Some of these goals could be summarized as follows:

- The patching mixture to be used should have such consistency at the time of application that it can be placed readily in the pavement holes without compaction.
- The mixture must adhere firmly to the various types of surface or base courses.
- The mixture must have sufficient stability and wear resistance.
- The mixture must possess the ability to set rapidly so that there will be no traffic delays.
- The patching operation should be safe to the workers.
- The repair should result in longer life than the conventional methods presently employed. It should last at least as long as the surrounding pavement.

- The patching material and operation should be economical.

There is one kind of bituminous concrete which has been widely known in European countries. This mixture is called "Gussasphalt" or as known in the United States "pourable bituminous concrete" or mastic asphalt. This mixture has the characteristics which closely satisfy the goals mentioned above. In this project, mastic asphalt concrete was evaluated in the laboratory for possible use in potholes and other pavement repairs.

Introduction to Mastic Asphalt

Gussasphalt or mastic asphalt concrete is a pourable concrete which does not need rolling or compaction after placement. It has several advantages over conventional bituminous mixtures which were best summarized by Fluss (1) as " the most durable, high cohesion strength, high abrasion resistance, less dependent on the weather during construction, no compaction required, and simple to maintain ". The hot mixture can be poured in place to a certain elevation to produce a voidless long life pavement (or patch) that has high skid resistance and low maintenance cost. Mastic asphalt can be used in roads subjected to very high traffic because it can have both high stability and durability (2).

A disadvantage in the use of mastic asphalt is that it requires long mixing time at about 430 F and special field delivery equipment, because it has to be placed at high temperature.

LITERATURE REVIEW

Mastic asphalt was first used in Europe early in the Nineteenth Century. France used it for sidewalks and bridges. The first poured pavement surface was constructed in England about 1836 (5).

Mastic asphalt has been used in Germany for a long time including wearing courses to rehabilitate the Autobahns. Experience has shown that if the stability of mastic asphalt is varied it could be used for widely different purposes. To provide stability and ease the paving process, coarse aggregate was introduced (3).

Mastic asphalt was mass produced and machine laid for the first time in 1953 in Berlin, Germany (5). It was placed on the German Autobahns for the first time during the following year. Approximately 1500 miles of Autobahn lanes have been paved with mastic asphalt. One of the reasons for the increased use and wider acceptance of the mastic asphalt as a material for road surfaces was the requirement that a paving contractor in Germany must guarantee his work for five years (5). After these successful trials in Germany, steady increase in the use of mastic asphalt occurred, not only in Germany, but also in other European countries. The first mastic asphalt application in the United States was first done in 1972 by Pennsylvania Department of Transportation, which let a contract involving resurfacing of 1.8 miles of US 322 between Harrisburg and Hershey. Michigan State Highway Department also laid a mastic asphalt test section in late 1972 (3-5). The placements in U.S.A. were not overly successful.

Mix Characteristics

Mastic asphalt can have a wide range of mix proportions and is generally within the following limits:

	Min.	Max.
• Coarse Aggregate, percent passing 1/2" and retained on No. 4 sieve ------------------------	0	50
• Fine Aggregate, passing No. 4 and retained on No. 200 sieve ------------------------------	20	60
• Filler, percent passing No. 200 sieve ------------	15	30
• Asphalt Cement (% by weight of mix) -----------	6	12

This range of aggregate gradations was generated from previous publications on mastic asphalt (3,4,5,6,13). The different proportions that were used in this study will be shown below.

A. Coarse and Fine Aggregate Properties

Coarse and fine aggregates are used as a basic solid matrix to regulate the stability of a mix. The thinner the asphalt film in the mix the higher the stability. Crushed coarse aggregate and natural sand is the combination most frequently encountered in the preparation of mastic asphalt.

The gradation of aggregate that were used in this project is shown in Table 1. This gradation was chosen by comparing some of the previous research done on mastic asphalt and also by taking into consideration the gradation limits that were suggested by the Lake Asphalt and Petroleum Company (3). In this project, the coarse aggregate was crushed gravel and the fine aggregate was natural sand.

B. Filler (Fly ash)

The filler material can be obtained from stone or gravel or any material that produces a suitable homogeneous bituminous mixture when mixed with asphalt on about five to one basis (4).

Unlike regular bituminous concrete which has about 5% filler, mastic asphalt may have 25% or more. This high amount of filler affects the mixture properties greatly. On mixing, dust particles get coated by the bituminous binder which causes the mixture to have a firm dense body that has low temperature susceptibility with high cohesive and adhesive characteristics (6).

Craus et. al. (7) studied the effects of physico-chemical properties of filler on bituminous mixes. They found that for most types of fillers, there is a general trend towards high intensity of adsorption of asphalt to the fine filler particles. They concluded that this effect causes a strengthening of the filler-bitumen bonds and a relative increase in the amount of fixed bitumen, which affects the strength and other properties of the mixture.

Anderson and Goetz (8) found that the size (gradation) and mineralogy of the filler has a great effect on the asphaltic mixture where consistency is controlled by the volume filling and physico-chemical reinforcing nature of the filler rather than by mineral to mineral contact.

Fly ash appears to be a reliable filler because its gradation does not vary greatly from plant to plant. It is also easily available and not costly.

Fly ash is a well known artificial pozzolan widely used in civil engineering. It is a powdery, largely inorganic by-product of the combustion of pulverized coal in electricity generating power plants. It is removed by mechanical collectors or electrostatic precipitators as a fine particulate residue from the combustion gases before they are discharged into the atmosphere (9,10).

Fly ash consists of a very fine graded particles, the majority of which are glassy spheres, with the remainder being crystalline matter and carbon. The size of particles range from 1 to 100 microns in diameter for glassy spheres with an average of 7 microns, and from 10 to 300 microns in diameter for irregularly shaped carbon particles (11). It should be added that high carbon fly ash can be used in the mastic.

Fly ash was used as a filler in this project as in Table 2.

C. Asphalt Used in This Study

As suggested by The Lake Asphalt Co. specifications, the asphalt binder used should not be very soft. The asphalt binder they recommend is a blend of AC-20 asphalt cement (40-60 penetration range) and 20-25% natural Trinidad asphalt (3). On the other hand Csanyi (6) reported that a bituminous mastic composed of fine mineral dust and soft binder, 150-200 penetration asphalt cement, has desirable physical characteristics with low temperature susceptibility and high cohesive and adhesive strengths. Douglas and Tons (12) also used 150-200 penetration asphalt. One practical reason for using softer asphalt is to make allowance for drop in asphalt penetration during the heating and mixing process.

In this project, an asphaltic binder with a penetration of 180 was used.

Mixing Equipment

The equipment used to mix mastic asphalt was made (and loaned to The University of Michigan) by the Michigan Department of Transportation and consisted of the following (see Figure 1):

- a circular pot eleven inches in diameter and eight inches in height rests on a heating unit
- an oil jacket that surrounds the pot
- the pot had two openings at the top, one 1/2" diameter for putting in nitrogen (if needed), and one for placing aggregates during mixing
- heating equipment that can go as high as 700 F
- a gear box that can go as low as 2, and as high as 15 rpm
- a strong concentric mixing paddle (see Figure 2)

The purpose of using this kind of equipment was to be able to coat completely with asphalt the surfaces of all aggregates, and also to ensure that no air (or very low amounts) is entrapped within the mixture.

Mixing Procedure

Different procedures can be used for preparing mastic asphalt. In this project two methods were used and compared. It was found that not much differences exist between them. For practical purposes Method 1 is recommended due to the fact that Method 2 requires rapid premixing.

a. Method 1

- Decide on total mixing time and the batch size and weights.
- Heat the oil in the jacket of the mixing pot to 430 F.
- Weigh out gravel, sand, and filler.
- Heat aggregates and asphalt to 430 F.
- Pour hot asphalt in the mixing pot first.
- Add all hot sand to the mixing pot.
- Mix until all the sand particles are coated with asphalt.
- Add half the filler. (preheated to 430 F)
- Mix until the mixture is all black.
- Add the other half of the filler and continue mixing.
- Add the coarse aggregate halfway through the total mixing time.
- At the end of mixing time the mix should have a shiny black appearance when relaxed and a dull appearance when strained.
- Grease Marshall molds and heat them at 430 F for 15 minutes, and fill them with mastic asphalt.
- No compaction is needed.

- Allow specimens to cool overnight. Then remove from mold for testing.

b. Method 2

- Decide on total mixing time.
- Heat the oil in the jacket of the mixing pot to 430 F.
- Weigh out gravel, sand, and filler.
- Mix sand and filler cold.
- Heat sand and filler mixture to 430 F.
- Heat asphalt to 430 F.
- Heat the coarse aggregate to 430 F.
- Mix the sand, filler, and asphalt at 60 rpm for 2 min.
- Put the mixture in the preheated mixing pot (at 430 F).
- Add the coarse aggregate halfway through the total mixing time.
- At the end of mixing time the mix should have a shiny appearance when relaxed and a dull appearance when strained.
- Grease Marshall molds and heat them at 430 F for 15 minutes, and fill them with mastic asphalt.
- No compaction is needed.
- Allow specimens to cool overnight. Then remove from mold for testing.

Strength Criteria

The strength of mastic asphalt is attributable to visco-elastic properties of the asphalt binder in thin films and due to the interlocking and friction between aggregate particles.

The shear strength of mastic asphalt depends partly on the ability of the asphalt binder to flow. Sommer (13) studied the effect of thin bituminous films and pointed out that these films follow the Law of Poiseuille relating to capillary flow:

$$V = \pi \times p \times a^4 / 8 \times L \times n$$

where:

V = volume of flow flowing through the capillary per second

L = length of capillary

p = pressure head over length L

n = absolute viscosity

a = capillary radius.

Inspection of the above volume of flow equation shows that the tendency to flow is inversely proportional to the absolute viscosity and proportional to the fourth power of the capillary radius. Obviously then the smaller the capillary (the thinner the asphalt film) and the higher the absolute viscosity, the greater the resistance to flow (12), which means that the capillary radius (or the film thickness) is the most influential parameter.

As mentioned above, aggregates play a very important role in achieving strength. Interlocking and internal friction of aggregates contribute to the shear strength. This is due to the fact that aggregate particles puncture asphalt films under load. This punctured asphalt film establishes mineral to mineral contact over a number of minute contact areas causing internal friction, which in turns increases the strength (12).

Film Thickness Concept

The concept of film thickness and its influence on the behavior of the asphalt mixture has been known for some time. Douglas and Tons (12) studied the effect of film thickness on the behavior of mastic asphalt. They concluded that adsorbed layer of asphalt on the surface of the aggregate behaves differently from the rest of the asphalt. When the film thickness between particles is so small as compared with the thickness of the adsorbed layer, it is then possible that this film behaves more rigidly and thus an apparent internal friction could be developed. By calculating the surface area of aggregates and by knowing the asphalt content, they were able to determine the film thickness. Also, they discussed the effect of close packing of particles and concluded that this kind of packing will force the film thickness to be low.

Csanyi (14) discussed the advantages of the thin film in connection with low temperature mixtures. He found that even if we have a thin film, adhesion may be secured between mixtures and a cleaned surface of old roads. Campen (15) pointed out that the average film thickness of 6 to 8 microns produces a durable bituminous concrete.

Failure Mechanism

As for the nature of the failure of a bituminous mixture under load, Mack (16) gave a detailed explanation on the deformation mechanism and the bearing strength of bituminous pavements. The bearing strength is the maximum load per unit area which a bituminous pavement can carry without causing the initial failure.

In the Marshall Stability Test, the basic difference between regular bituminous mixtures and mastic asphalt mixtures is that mastic asphalt does not "fail", and the load goes up with increased deformation. For example a flow of 50 could be obtained and the specimen would continue to take more load without failure. On the other hand, regular bituminous concrete usually fails at a flow of 20 or less. A plot for the stability versus flow for a typical mastic asphalt mixture could be seen in Figure 3.

This behavior could be explained by the fact that regular bituminous concrete has voids, and beyond the bearing strength cracks start to generate where voids make it easier for a crack to travel through a specimen, after which failure occurs. However, mastic asphalt concrete has no voids and all the aggregates are coated with asphalt binder; this means that under displacement the material deforms but cracks has no place to generate and travel and the material continues to squeeze like an incompressible material and take more load.

During the tests the load on a typical mastic asphalt Marshall specimen continued to increase with the displacement, and the Marshall testing machine was stopped just before the jaws that hold the Marshall specimen almost touched each other. The flow value at the time the jaws can touch each other is 60. The stability in this experiment was measured and recorded at Marshall flow of 20 and 45.

Testing Program

The purpose of this test program was to make various mixes and run selected tests to study mastic asphalt suitability for pavement hole patching. The following variables and levels were used in materials and mixing:

VARIABLE	LEVELS
• Coarse Aggregate Content	3*
• Filler Content (Fly Ash)	3*
• Asphalt Content	3
• Mixing Time	3

* Coarse Aggregate + Filler + Sand = 100%.

The combination of the above variables would require 3^4 or 81 mixes. A statistical model was chosen to decrease the number of experiments made without losing much information. This model is called the "Latin Squares design". Following this design 27 mixes were needed instead of 81. A clear explanation of the model is shown in the following:

Having four variables with three levels each, the coding was done in the following manner:

Asphalt (%)	Fly Ash (%)	Gravel (%)	Mix Time (hrs)
D1 = 9	A1 = 15	B1 = 0	C1 = 1
D2 = 10.5	A2 = 22	B2 = 15	C2 = 3
D3 = 12	A3 = 30	B3 = 30	C3 = 5

	D1			D2			D3		
	A1	**A2**	**A3**	**A1**	**A2**	**A3**	**A1**	**A2**	**A3**
B1	C1	C2	C3	C2	C3	C1	C3	C1	C2
B2	C2	C3	C1	C3	C1	C2	C1	C2	C3
B3	C3	C1	C2	C1	C2	C3	C2	C3	C1

For example D1 **A1** ***B1*** C1 is one mix, D1 **A1** ***B2*** C2 is another mix and so on. This means that there are nine mixes with D1, nine mixes with D2 and nine mixes with D3. Also, nine mixes with each of **A1**, **A2**, and **A3**, ***B1***, ***B2***, and ***B3***, C1, C2, and C3 for a total of 27 mixes.

To evaluate the asphalt main effects (or single way interactions), for example, add all nine values under D1 and average them to get one point, all values under D2 to get another point, and all values under D3 to get a third point. Having these points of a certain property allows to plot that property, say Marshall Stability, versus asphalt content. Moreover, since this model is orthogonal, two and three way interactions and their effects for any test can be studied. Each mixture in this experiment was selected at random. The measurements made are shown below:

	TESTS MADE	TEST TYPE
•	Pourability	______
•	Voids and VMA	Non-Destructive
•	Resilient Modulus	Non-Destructive
•	Marshall Stability	Destructive
•	Freeze-Thaw and	Non-Destructive
•	Water Immersion	(done only for certain mixes)

SUMMARY OF TESTS

The summary of the testing procedures used in this project is given below:

1-Pourability

Pourability is fluidity of the mix. It is the ability of a mixture to flow or travel into a pothole or a crack. Pourability was measured on a subjective scale of 0 to 10, where a mix with grade value of 0 has no pourability, and a mix with grade value of 10 has excellent pourability but segregation of aggregates may occur. A mix with grade value > 5 is considered to have enough pourability to travel into a pothole.

2-Specific Gravity Using Marshall Size Specimens to determine BSG, VMA, and Voids

- Weigh specimen in air and in water
- Specific Gravity = weight in air / {weight in air - weight in water}.
- Starting from this, % voids and % V.M.A were calculated.

3-Resilient Modulus Using Marshall Size Specimens

Resilient Modulus procedure is a non destructive test that uses a Marshall size specimen to determine the resilient modulus (17). This test was done as follows:

- The thickness of the specimen in dry condition was measured at 77 F.
- 0.1 second duration pulsating load of 30 and 50 lbs was applied across one diameter of the specimen.
- At the same time, the elastic deformation was measured across the opposite diameter.
- Two measurements on each specimen were performed.

The resilient modulus, M_r, is then calculated from the following equation:

$$M_r = \{P(\nu + 0.2734)\} / (t \times \Delta)$$

where:

P = Applied load (50 lb)

v = Poisons ratio (0.35 was assumed)

t = Thickness of the specimen (in)

Δ = Elastic deformation (in)

4-Marshall Stability

For the mastic asphalt specimens the following procedure was used:

- Pour mastic asphalt into Marshall mold at 430 F.
- Remove specimen from molds after 24 hours at room temperature.
- Store specimen at room temperature for 6 days.
- Put specimen for 1/2 hour in a water bath at 140 F before ` testing.
- Run Marshall test.
- Read the values of stability at flow of 20 and 45.

5-Freeze-Thaw and Water Immersion Using Marshall Size Specimens

The effect of water immersion and freeze-thaw action were measured using the resilient modulus apparatus and the following procedure:

- Resilient Modulus, M_r, was measured in dry condition at 77 F.
- Specimen was soaked in water at 140 F for 24 hours followed by cooling in 77 F water bath for 2 hours.
- M_r was measured again at 77 F.
- Soaked specimen was put in a plastic bag and placed in a freezer at 0 F for 8 hours followed by four hours of thawing at 77 F.
- Resilient Modulus, M_r, is then measured after ten cycles of freezing and thawing.

These tests were performed only on mixes #2, 11, and 23. These mixes have pourability of low, medium and high, respectively, which correspond to low medium and high void content.

RESULTS AND DISCUSSION

Mastic asphalt mixtures were made with 150-200 penetration asphalt. Altogether, 27 different mixes were studied varying the asphalt, sand, gravel, and filler (fly ash) content as well as the mixing time. The aggregate gradations for all 27 mixes are shown in Table 1. Mixtures proportions are listed in Table 3, and properties of the mixes are shown in Table 4. Stability and resilient modulus results are given in Table 5.

Following is a brief discussion of some of the trends and relationships that can be plotted. It must be remembered however, that mastic asphalt is a very complicated mixture and some of the statements below may be speculative.

The Marshall Stability test results are compared graphically in Figures 4 to 7. The values for stability were obtained at flow = 20 and flow = 45. The same general trend is observed in all figures for both flow=20 and flow=45.

Figure 4 shows stability versus asphalt content with the trend that stability decreases as asphalt content increases. This trend is as expected for a mastic asphalt mixture. In Figure 5, where the Marshall Stability versus fly ash content is plotted, the stability tends to increase and then decrease. This may be due to the fact that at low fly ash content thicker asphalt films decrease stability values. As fly ash content is increased asphalt film get thinner and stability goes up. With more increase in fly ash, the mix gets dry and air voids are introduced which reduces the strength of the mix.

Figure 6 shows stability versus gravel content. Stability increases with the increase in gravel quantity, but at a certain point, this curve will reach a maximum and then decrease afterwards because with increase in coarse aggregate there is a corresponding decrease in fine aggregate at which the asphalt film becomes thicker decreasing the stability of the mix.

Figure 7 shows that stability increases with the increase in mixing time. This is due to the fact that aggregates get coated better by the binder with longer mixing time, and also the asphalt gets harder with time. This phenomenon was studied for mix #11, and stability was plotted versus mixing time in Figure 8, where time varied from 1 to 11 hours. Notice that mixing time for this type of mix has a significant effect.

Stability is very important factor in bituminous concrete used in pavements layers. As far as potholes are concerned, stability may not be the most important factor. This is due to the fact that confinement imposed by the pothole walls adds to the stability of the mix especially in small to medium holes. However, for large potholes a stability of 400 or higher may be desirable to carry traffic loads.

The resilient modulus results are shown in Figures 9 to 12. Notice that these figures follow the same trends as Figures 4 to 7 due to the fact that, generally, higher Marshall stability goes with higher Resilient Modulus and vice versa.

The air void trends are shown in Figures 13 to 15. In Figure 13 the air voids are shown to decrease with increase in asphalt content. This trend was expected due to the fact that the asphalt binder will fill the existing voids. In Figure 14 air voids are shown to increase with the increase in fly ash. This is because increase in fly ash content seems to make the mix stiffer and dryer with more air voids. It can be observed from Figure 15 that with higher gravel content the air voids are lower because by increasing gravel content the amount of fine aggregate decreases and less air is entrapped between the larger particles of a mix.

In Figure 16, pourability is shown to increase with increase in asphalt content. This trend is expected. However, with increase in fly ash pourability decreases as shown in Figure 17. This is because with gain in fly ash the surface area increases and the film thickness decreases making the mix stiffer. Figure 18 shows that with increase in gravel content pourability increases slightly due to the reasons discussed above.

Figures 19 to 22 show the relation between VMA and asphalt content, fly ash, gravel, and mixing time, respectively. Figures 23 and 24 show the relation between bulk specific gravity and each of the fly ash contents and gravel content, respectively.

Figure 25 was plotted for the purpose of showing a relation between the energy under the Marshall load-flow curve and the pourability. Different selected mixtures were specially prepared for this purpose and tested using a Marshall testing machine connected to a plotter. Energy was found by calculating the area under the stability versus displacement (flow) curve. Areas were found between zero and flow=20 and between zero and flow=45. Since the pourability scale of 0-10 is subjective, Figure 25 can be used to relate the energy values with the pourability numbers.

For the specimens that were tested for freeze-thaw and water immersion, it was found that mixes which had pourability higher than 6 showed no damaging effects as could be seen in Table 6. For mix #2 with pourability=1, there was a noticeable change in resilient modulus. The damage was probably due to the large amount of voids in the specimen. Mix #11 with pourability=7 and mix #23 with pourability=10 showed basically no changes in the resilient modulus due to water immersion and freeze-thaw cycles.

Generally, mixtures with pourability less than 6 may not be considered a true mastic asphalt mixture any more since they contain high amount of voids. However, a mixture with pourability of 7 or higher would have basically no voids for the water to go into.

APPENDIX

Table 1. Gradation of Aggregate Used in Mixtures.

Sieve range	Weights used in a mix (grams)								
1/2 - 3/8	0	0	0	0	0	0	0	0	0
3/8 -#4	540	1080	540	1080	540	0	0	1080	0
#4 - #8	472	324	432	252	360	576	504	360	468
#8 - #16	630	432	576	396	504	792	720	504	648
#16 - #30	578	396	540	360	468	720	684	468	612
#30 - #50	525	360	504	324	432	684	648	432	576
#50 -#100	210	144	144	72	144	180	180	144	144
#100 - # 200	105	72	72	36	72	108	72	72	72
> #200 Fly Ash	540	792	792	1080	1080	540	792	540	1080
Total	3600	3600	3600	3600	3600	3600	3600	3600	3600
Mix numbers *	1 3 8	2 4 11	5 13 22	6 9 24	7 14 26	10 12 16	15 17 27	18 19 23	20 21 25

* Mixes for which the gradations were used in.

Specific Gravity of Sand = 2.60
Specific Gravity of Gravel = 2.63
Specific Gravity of Fly Ash = 2.334

Table 2

Properties of Fly Ash

Silica, SiO_2	55.2
Alumina,Al_2O_3	29.2
Iron, Fe_2O_3	6.0
Titanium, TiO_2	1.8
Calcium, CaO	1.3
Magnesium, MgO	1.0
Carbon, C	5.8
Specific Gravity	2.334

<u>Gradation</u>

Sieve Size	Percent Passing
#30	100
#200	99
#325	97
*20 microns	79
*10 microns	40
*5 microns	18

Table 3. Mixture Proportions

Mix Number	Asphalt Content (%)	Fly Ash Content (%)	Gravel Content(%)	Mixing Time (Hrs)
1	9	15	15	3
2	9	22	30	1
3	10.5	15	15	5
4	12	22	15	5
5	10.5	22	15	1
6	9	30	30	3
7	9	30	15	1
8	12	15	15	1
9	12	30	30	1
10	10.5	15	0	3
11	10.5	22	30	3
12	12	15	0	5
13	12	22	15	3
14	10.5	30	15	3
15	10.5	22	0	5
16	9	15	15	1
17	9	22	0	3
18	9	15	30	3
19	10.5	15	30	1
20	9	30	0	5
21	12	30	0	3
22	9	22	15	5
23	12	15	30	3
24	10.5	30	30	5
25	10.5	30	0	1
26	12	30	15	5
27	12	22	0	1

Table 4. Mixture Properties*

Mix Number	Bulk Specific Gravity	Unit Weight (lb/ft3)	VMA (%)	Air Voids (%)	Pourability
1	2.27	141.6	18.6	0.23	6
2	2.16	134.8	22.2	6.5	2
3	2.26	141.0	20.2	0	8
4	2.19	136.7	22.3	0	9
5	2.20	137.3	22.3	0.1	7
6	1.71	106.7	38.2	18.1	0
7	1.69	105.5	38.9	25.0	0
8	2.22	138.5	23.8	0	10
9	2.11	131.7	26.2	2.6	6
10	2.23	139.1	22.2	0	8
11	2.22	138.5	21.9	0.6	7
12	2.20	137.3	24.0	0	9
13	2.20	137.3	23.5	0	9
14	1.93	120.4	31.0	12.5	0
15	2.21	137.9	22.5	1.22	7
16	2.26	141.0	19.5	1.15	5
17	2.10	131.0	25.2	8.4	3
18	2.29	143.0	18.8	0.3	5
19	2.26	141.0	20.7	0	8
20	1.63	101.7	40.8	27.7	0
21	2.09	130.4	26.8	3.56	3
22	1.78	111.1	36.2	21.8	0
23	2.23	139.2	23.5	0	10
24	2.18	136.0	22.5	1.55	5
25	1.86	116.1	33.5	15.5	2
26	2.13	132.9	25.8	2.1	5
27	2.19	136.7	24.2	0	9

* All values are based on averages of three specimens except for pourability which is a measure for the whole mix.

Table 5. Stability and Resilient Modulus Results.

Mix Number	Marshall Stability at Flow = 20 (lbs) *	Marshall Stability at Flow = 45 or max, (lbs) **	Resilient Modulus X 1000 (psi) ***
1	366	711	55.7
2	575	575	92.9
3	209	470	50.3
4	52	167	35.0
5	261	543	42.3
6	376	387	98.9
7	136	136	50.0
8	63	105	17.1
9	240	449	53.1
10	105	251	25.3
11	418	669	74.8
12	73	178	23.7
13	94	136	19.8
14	354	366	84.3
15	157	334	30.5
16	219	554	42.4
17	596	627	213.9
18	564	940	96.8
19	115	282	31.0
20	366	387	80.3
21	303	512	45.5
22	982	1066	293.9
23	104	251	31.7
24	449	679	45.5
25	261	261	47.2
26	439	700	72.5
27	52	104	17.5

* Numbers correspond to averages of two specimens.

** Numbers correspond to averages of two specimens at flow = 45 or at maximum flow.

*** Numbers correspond to averages of three specimens

Table 6. Water Immersion and Freeze-Thaw Damage

	Resilient Modulus x (1000 psi) *		
Mr / Mix #	Mr-dry	Mr-wet	Mr- freeze &thaw
2	93.5	71.3	35.7
11	72.4	71.5	69.6
23	32.0	32.0	31.5

* results obtained by testing on one specimen from each mix

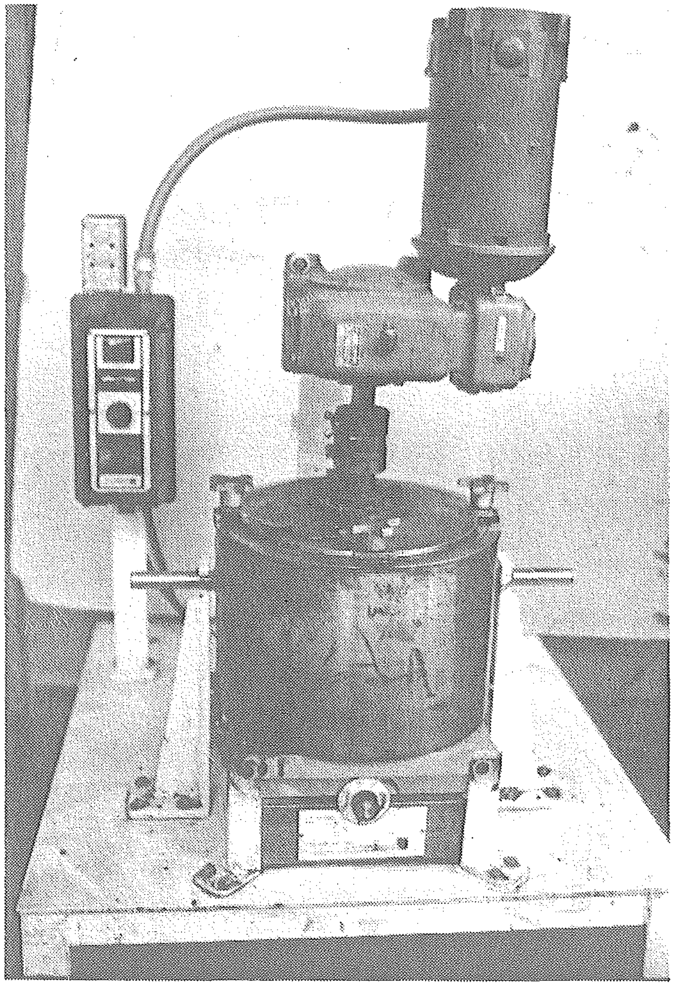

Figure 1. Mixing equipment used to make mastic asphalt

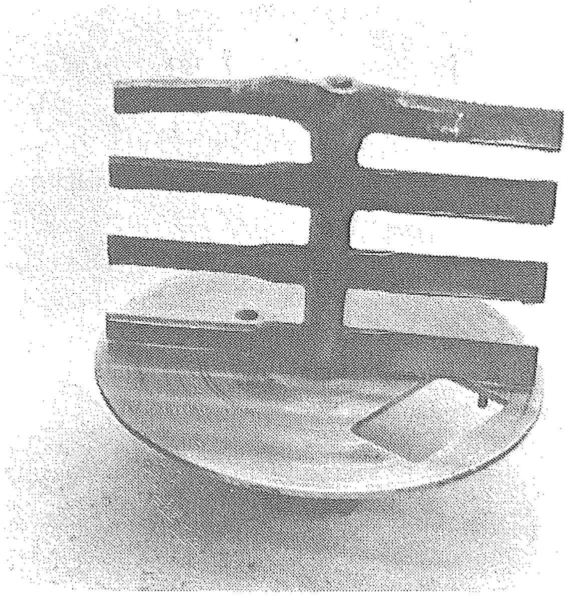

Figure 2. Mixing paddle

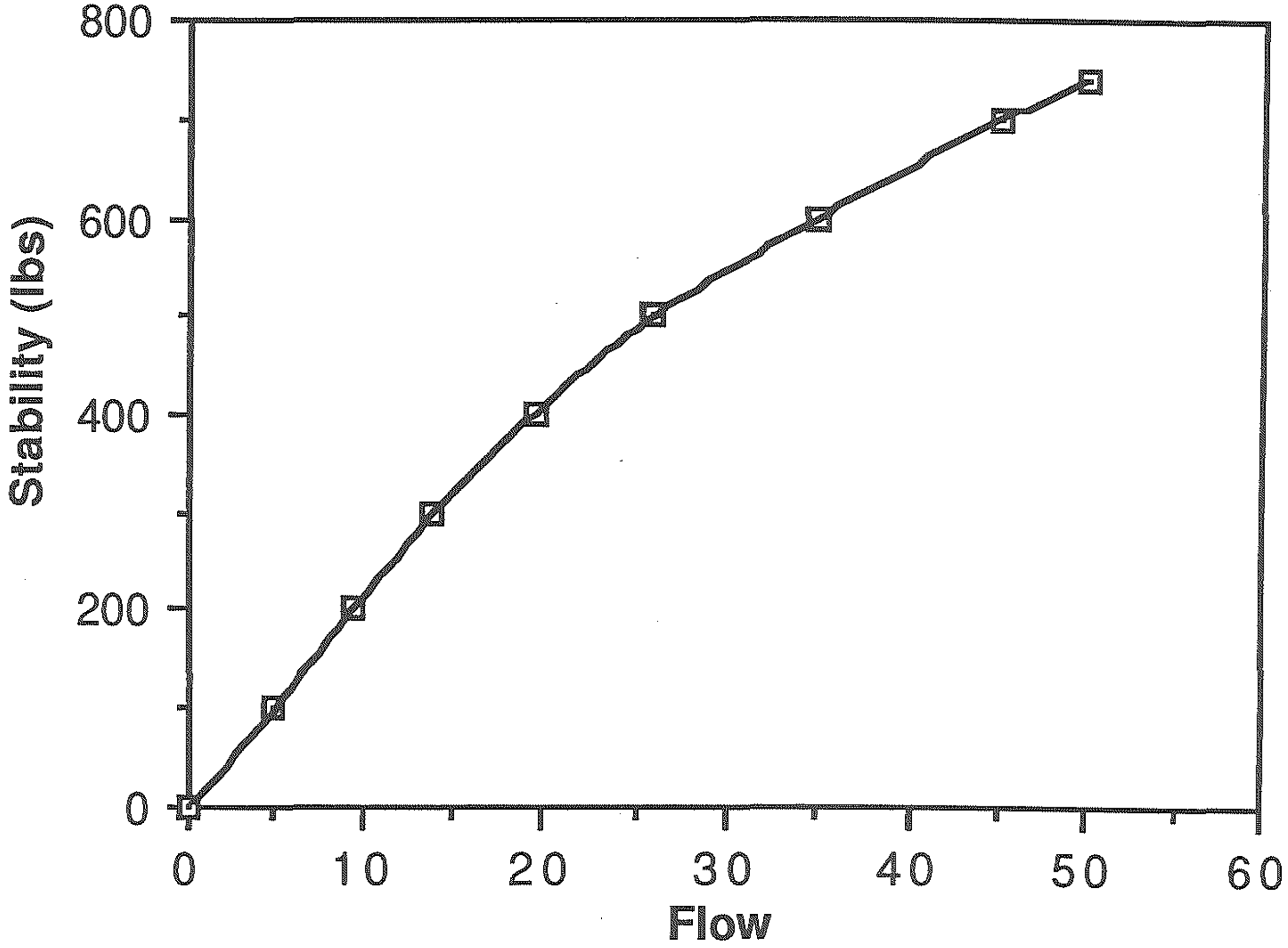

FIG 3. Stability vs. flow for a typical mix (mix #11)

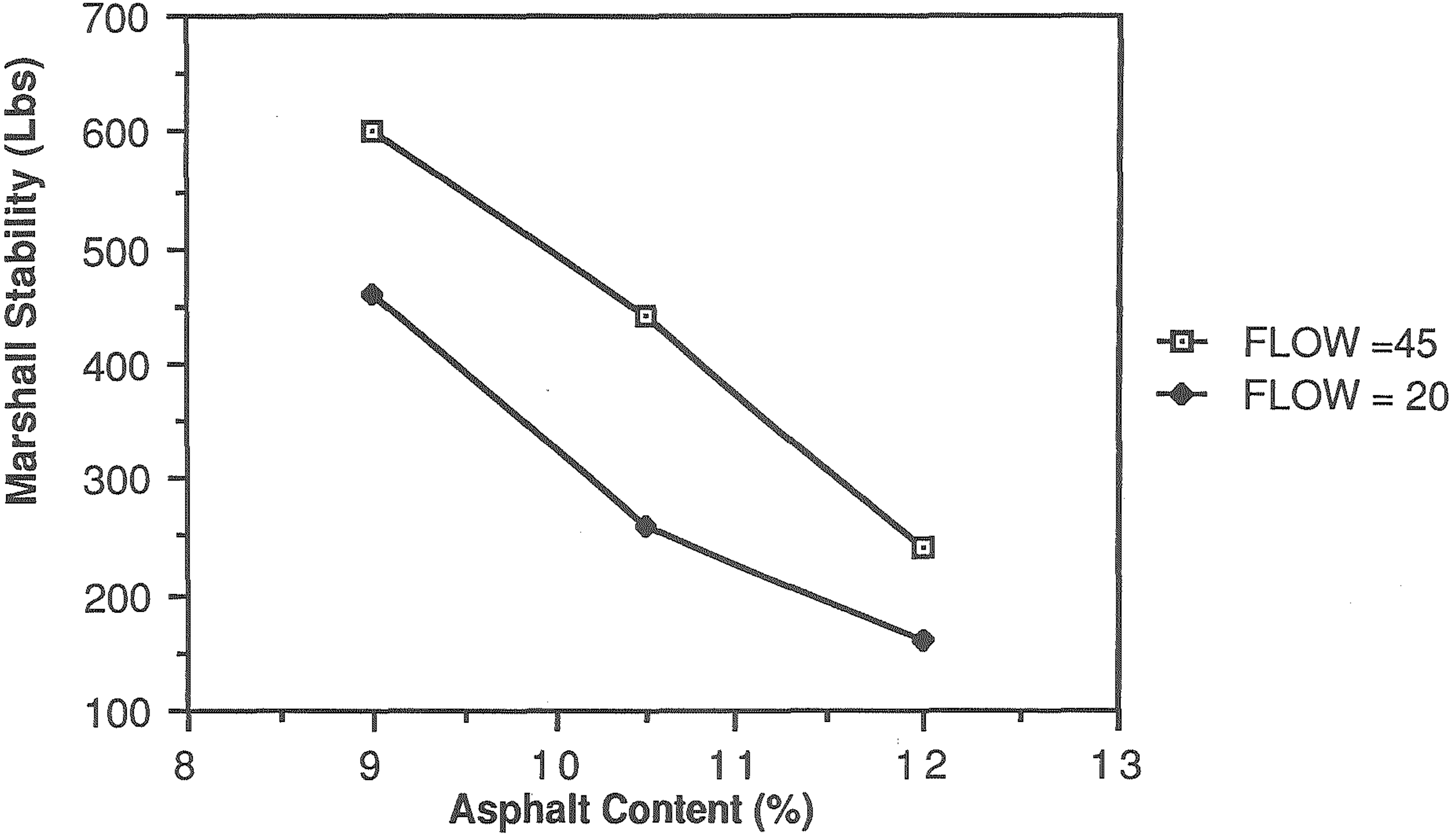

FIG 4. Stability vs. asphalt content, average trends

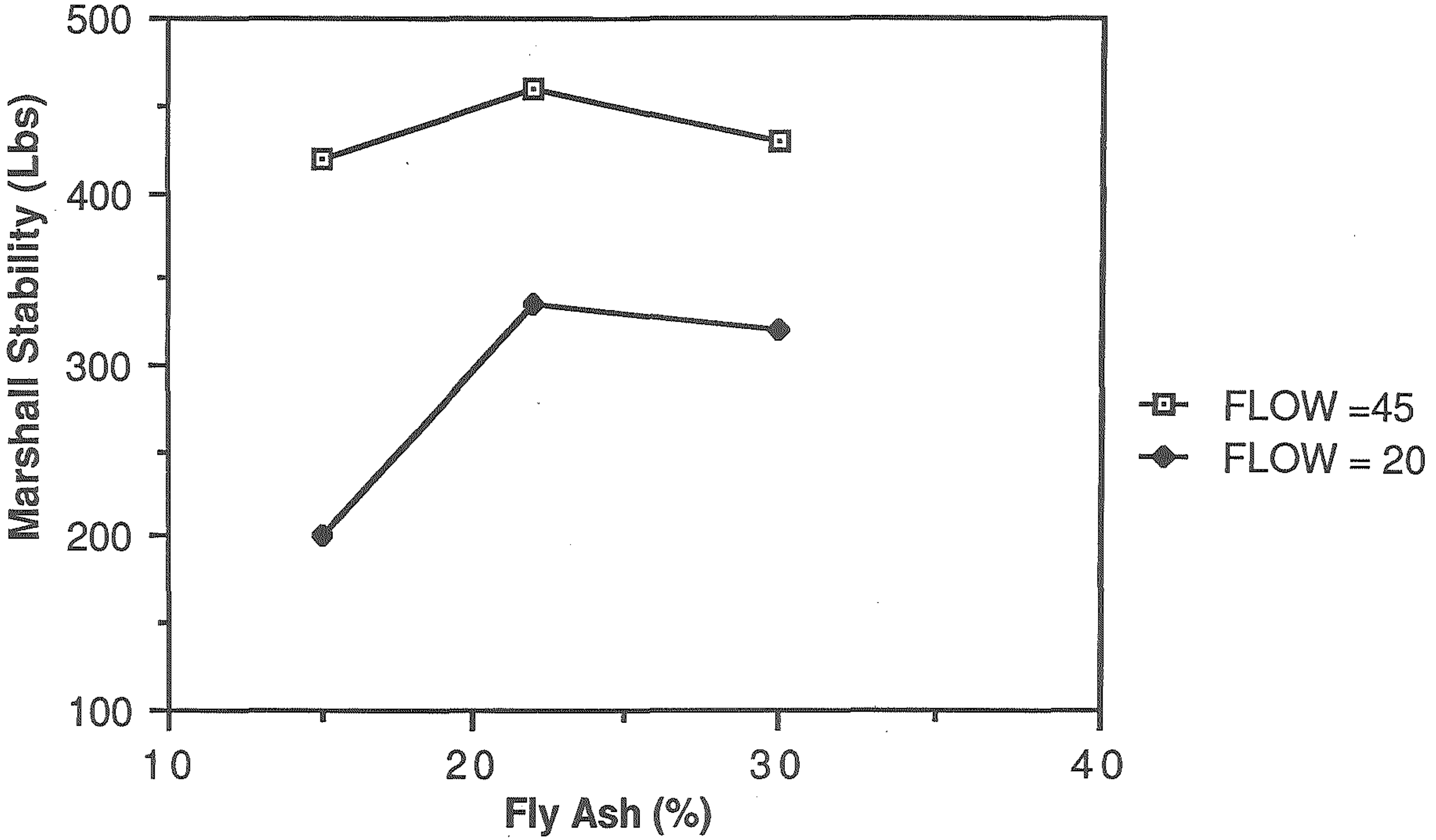

FIG 5. Stability vs. fly ash content, average trends.

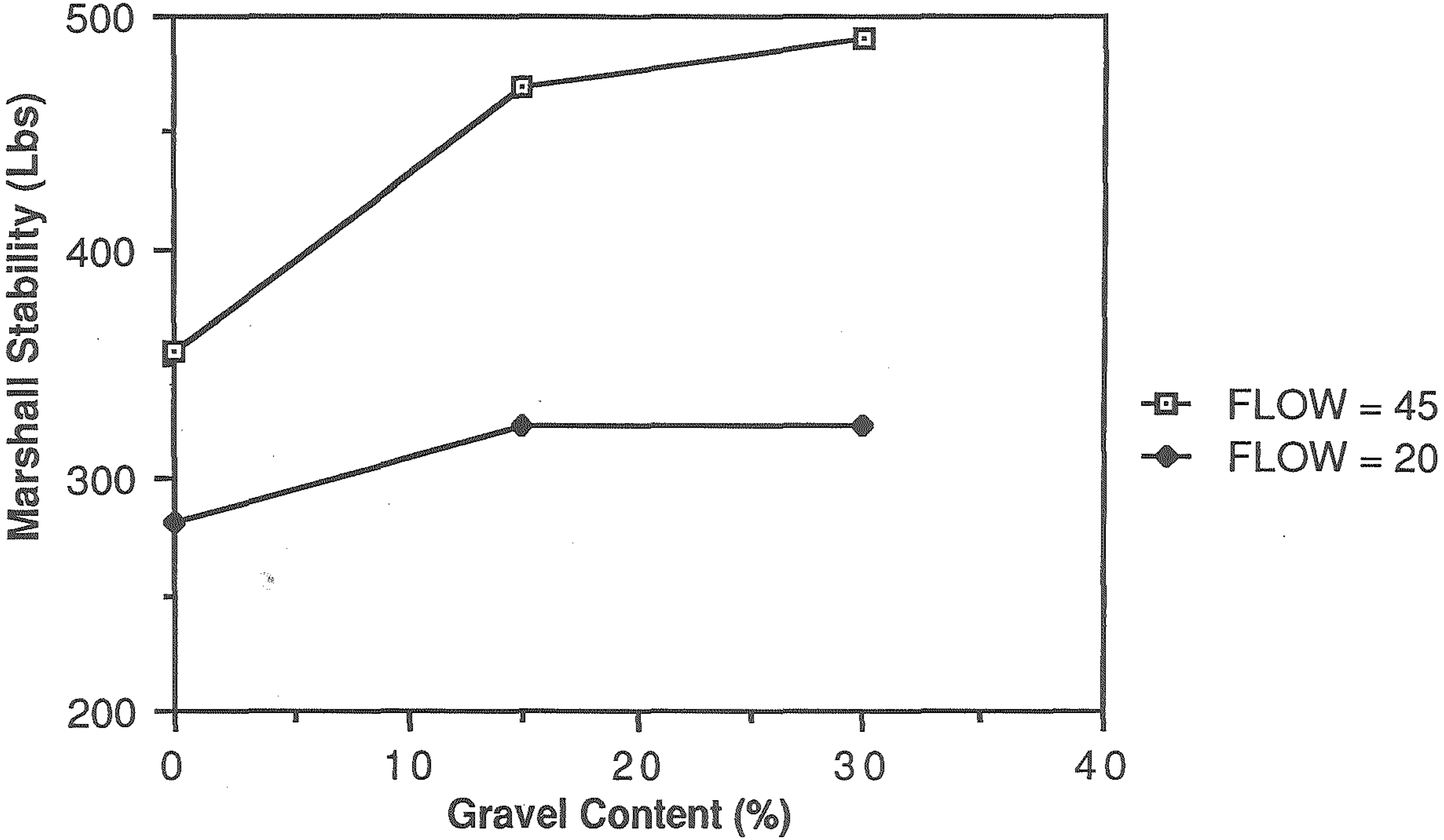

FIG 6. Stability vs. gravel content, average trends.

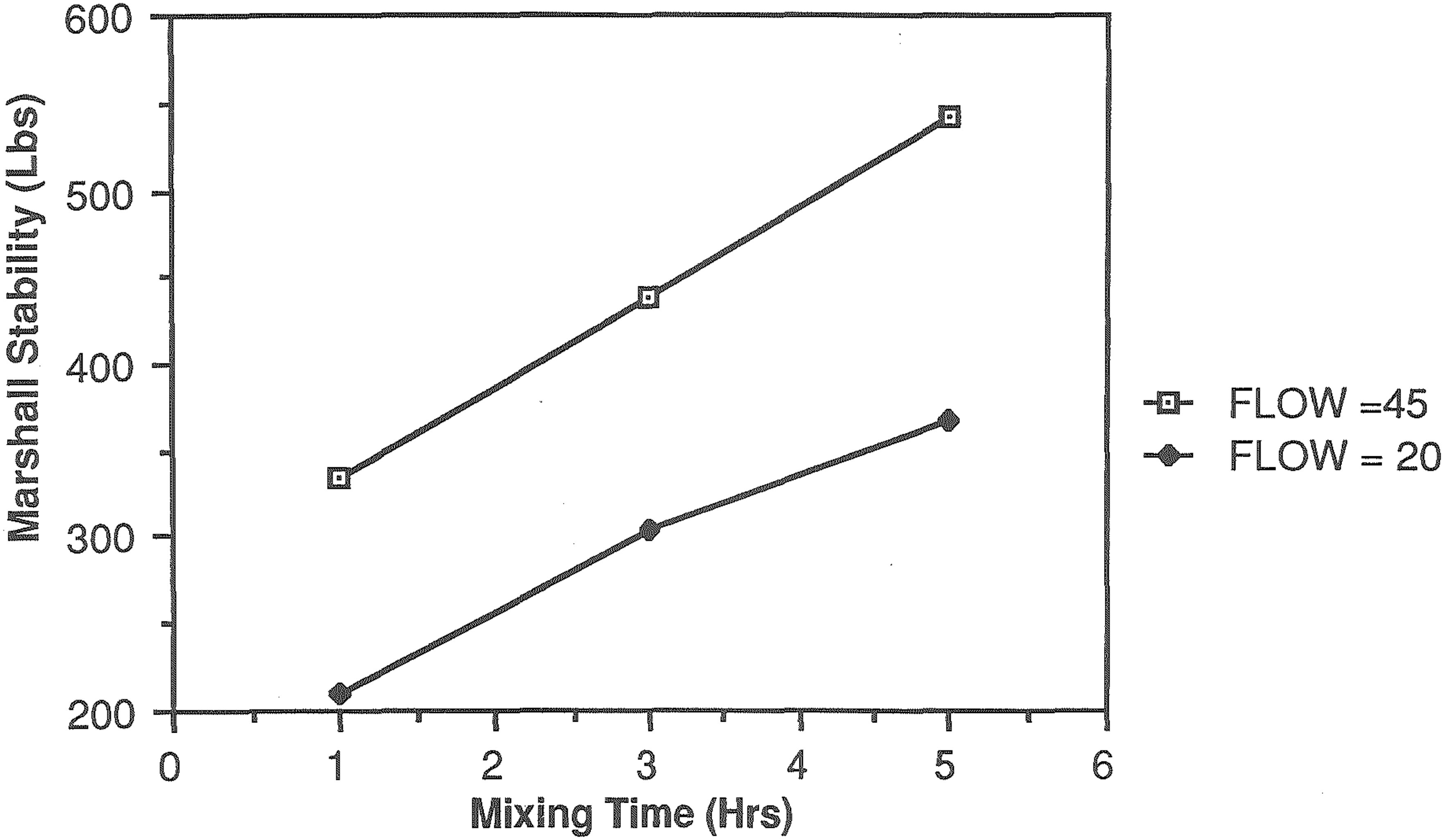

FIG 7. Stability vs. mixing time, average trends.

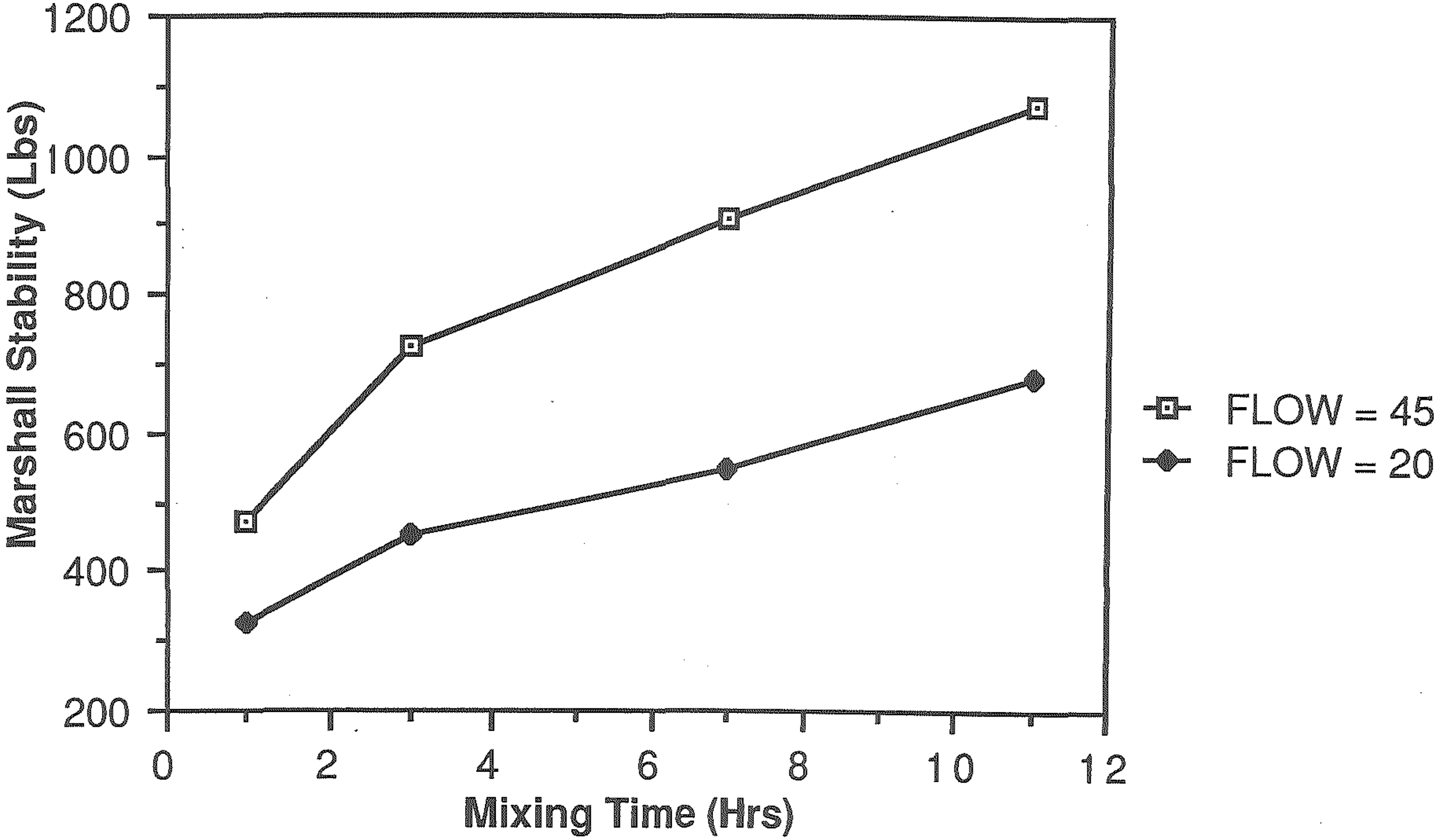

FIG 8. Stability vs. mixing time, specimens of mix #11.

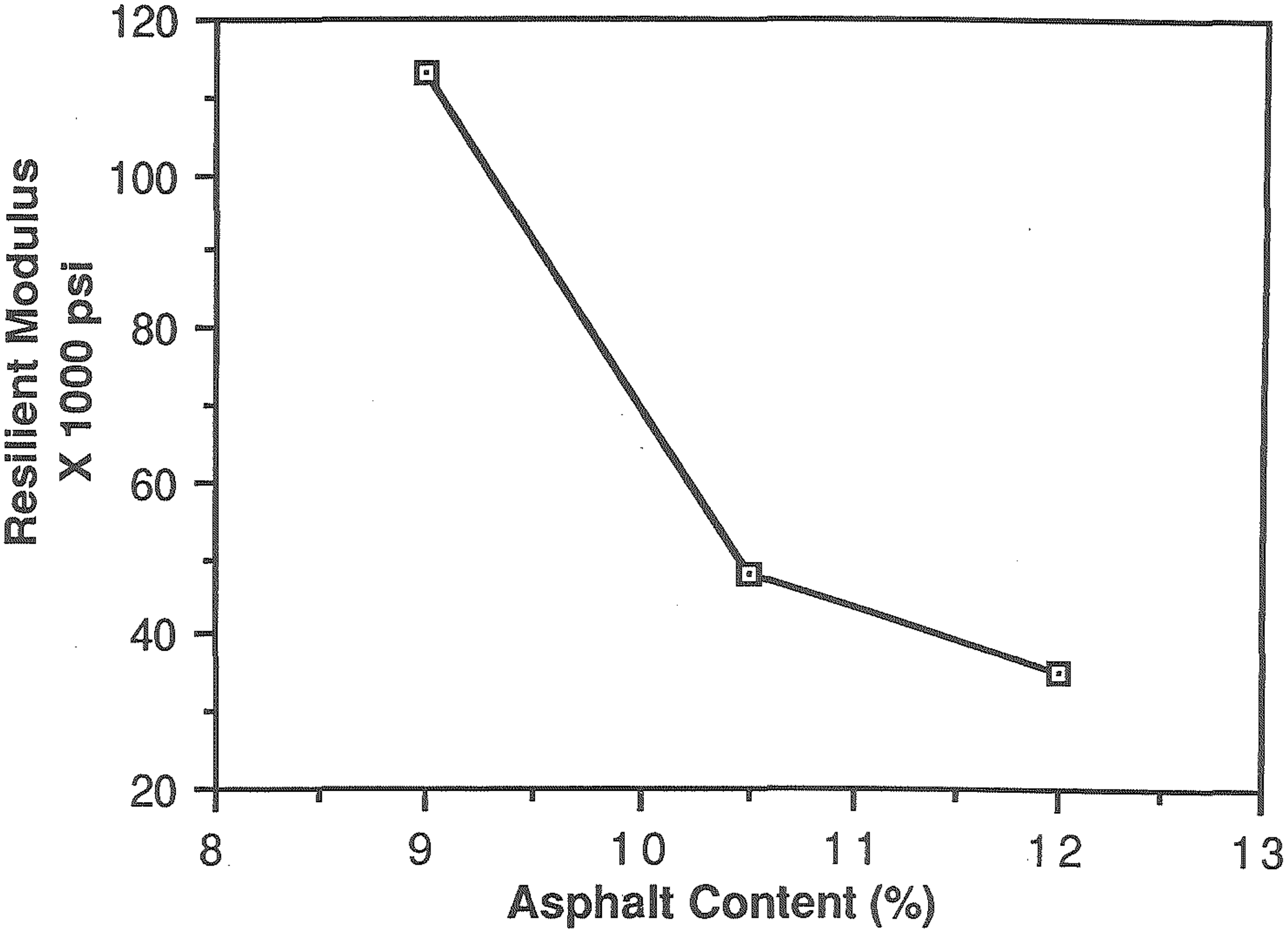

FIG 9. Resilient modulus vs. asphalt content, average trend.

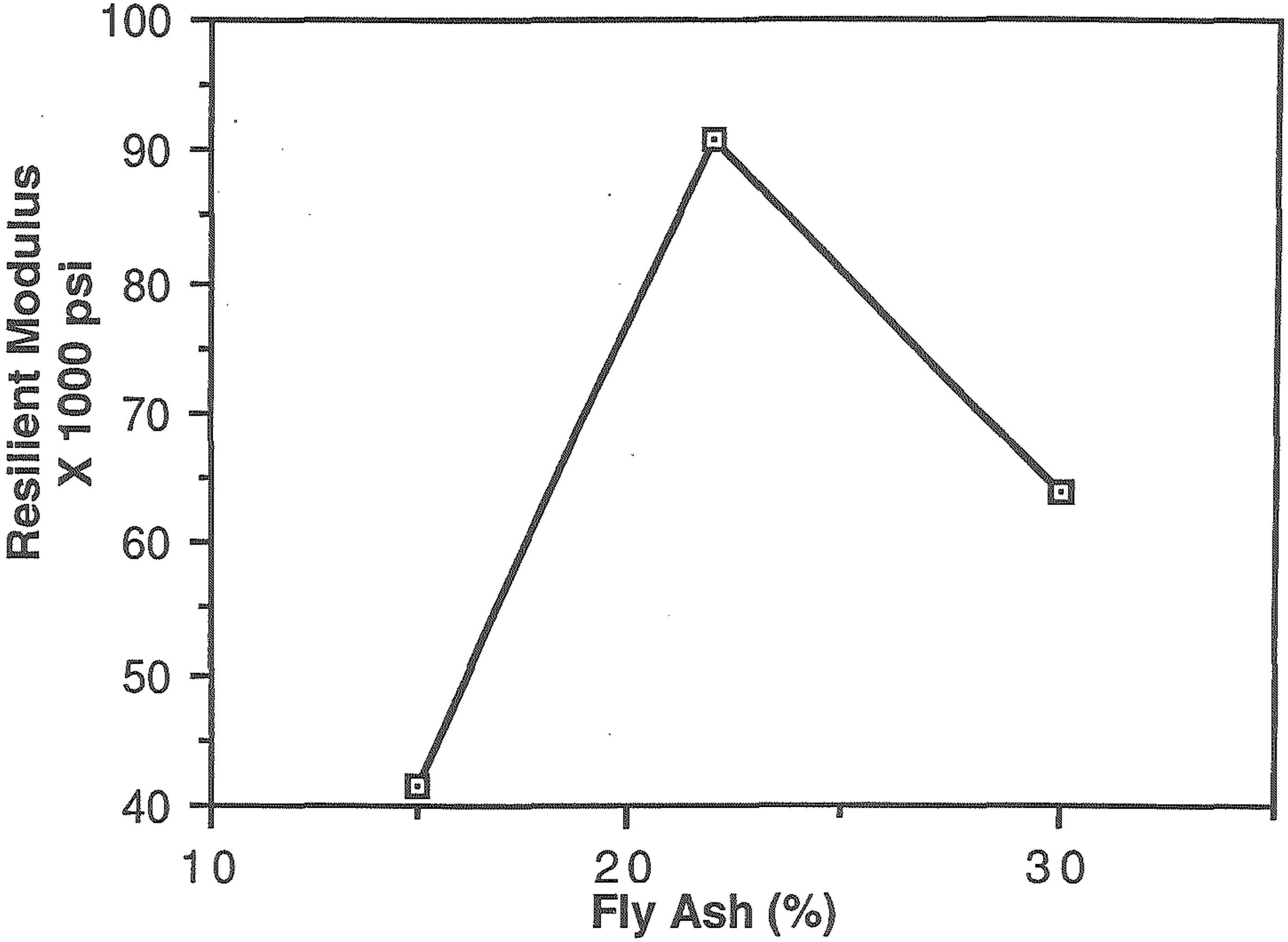

FIG 10. Resilient modulus vs. fly ash content, average trend.

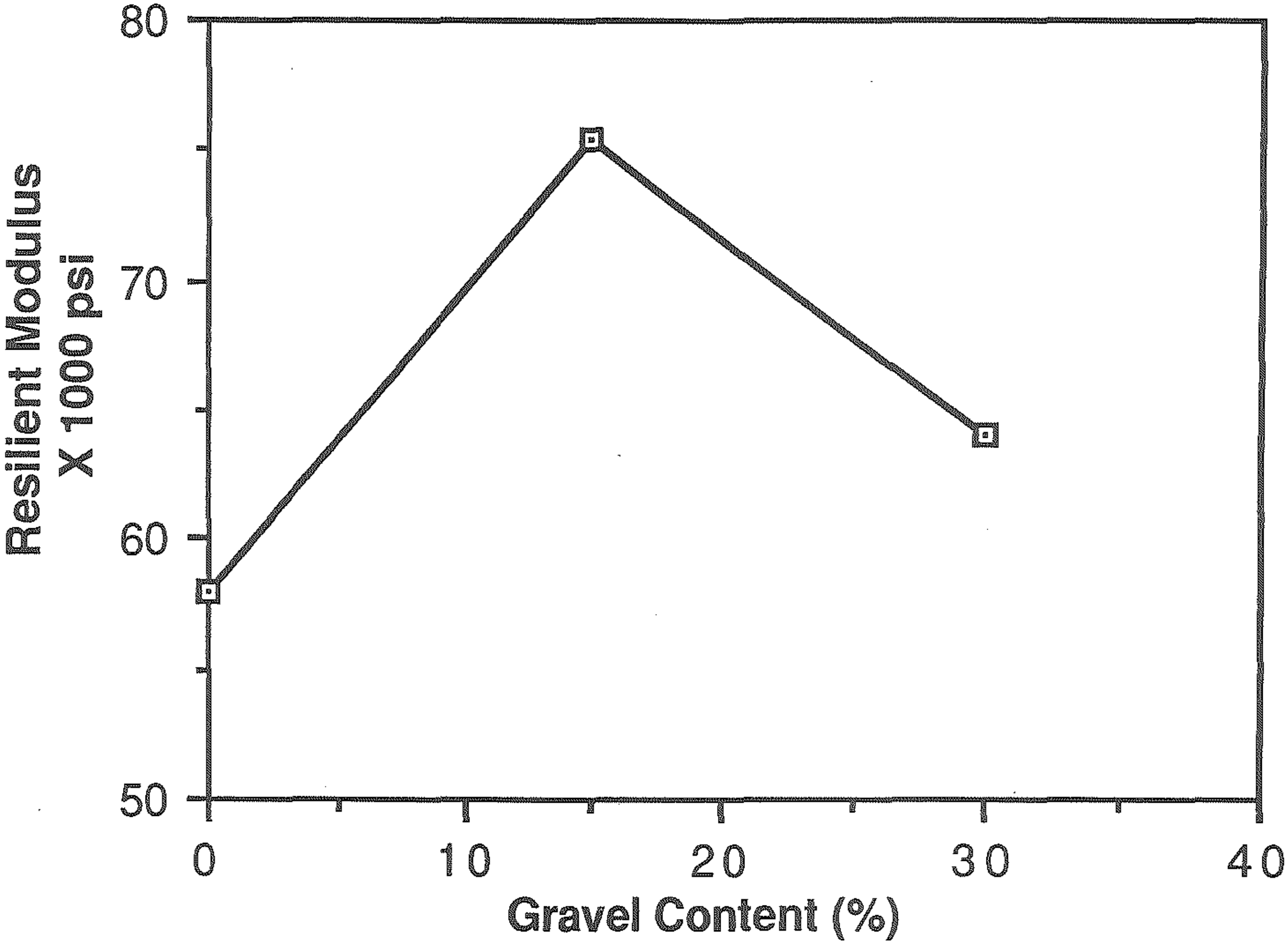

FIG 11. Resilient modulus vs. gravel content, average trend.

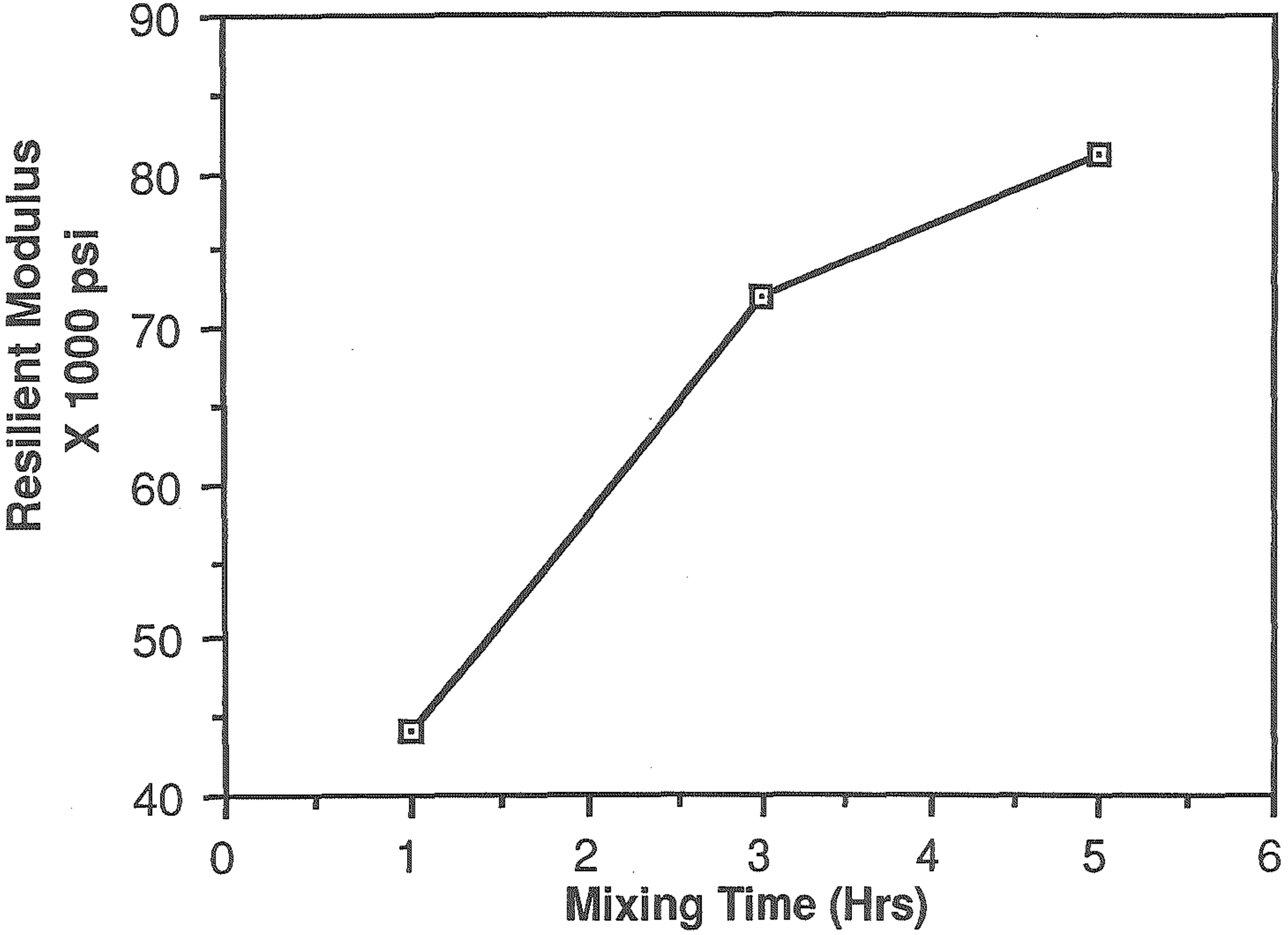

FIG 12. Resilient modulus vs. mixing time, average trend.

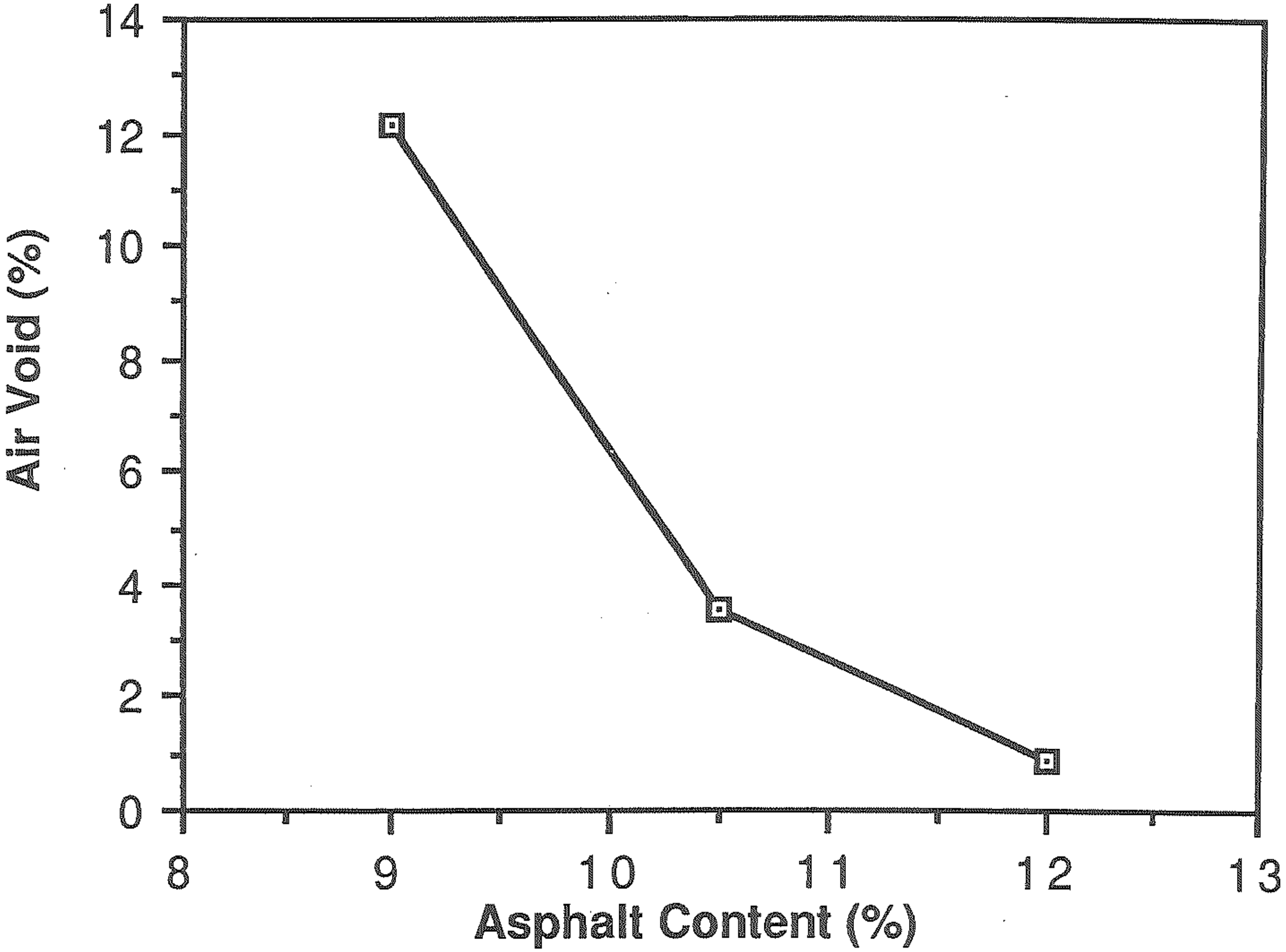

FIG 13. Air voids vs. asphalt content, average trend.

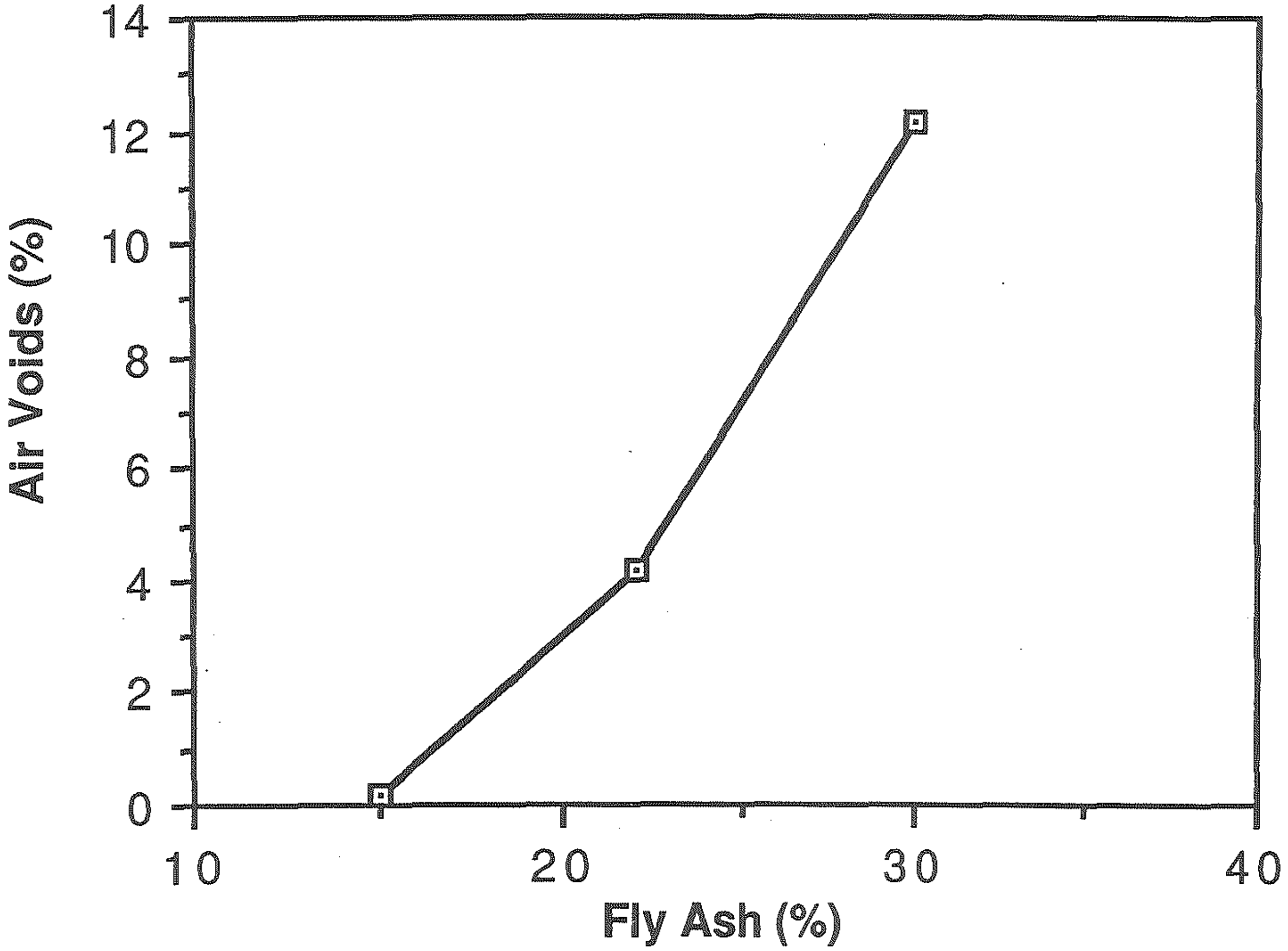

FIG 14. Air voids vs. fly ash content, average trend.

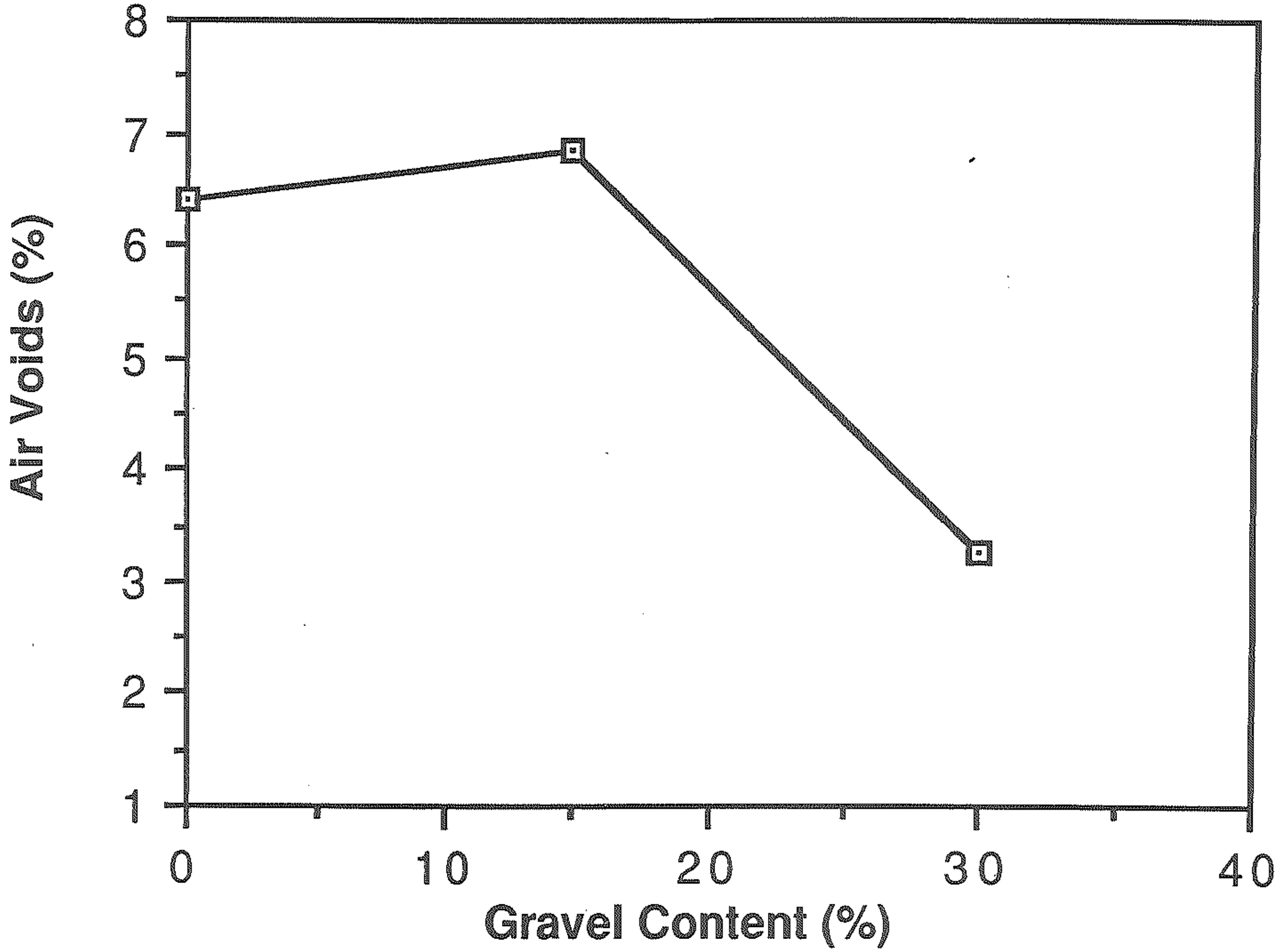

FIG 15. Air voids vs. gravel content, average trend.

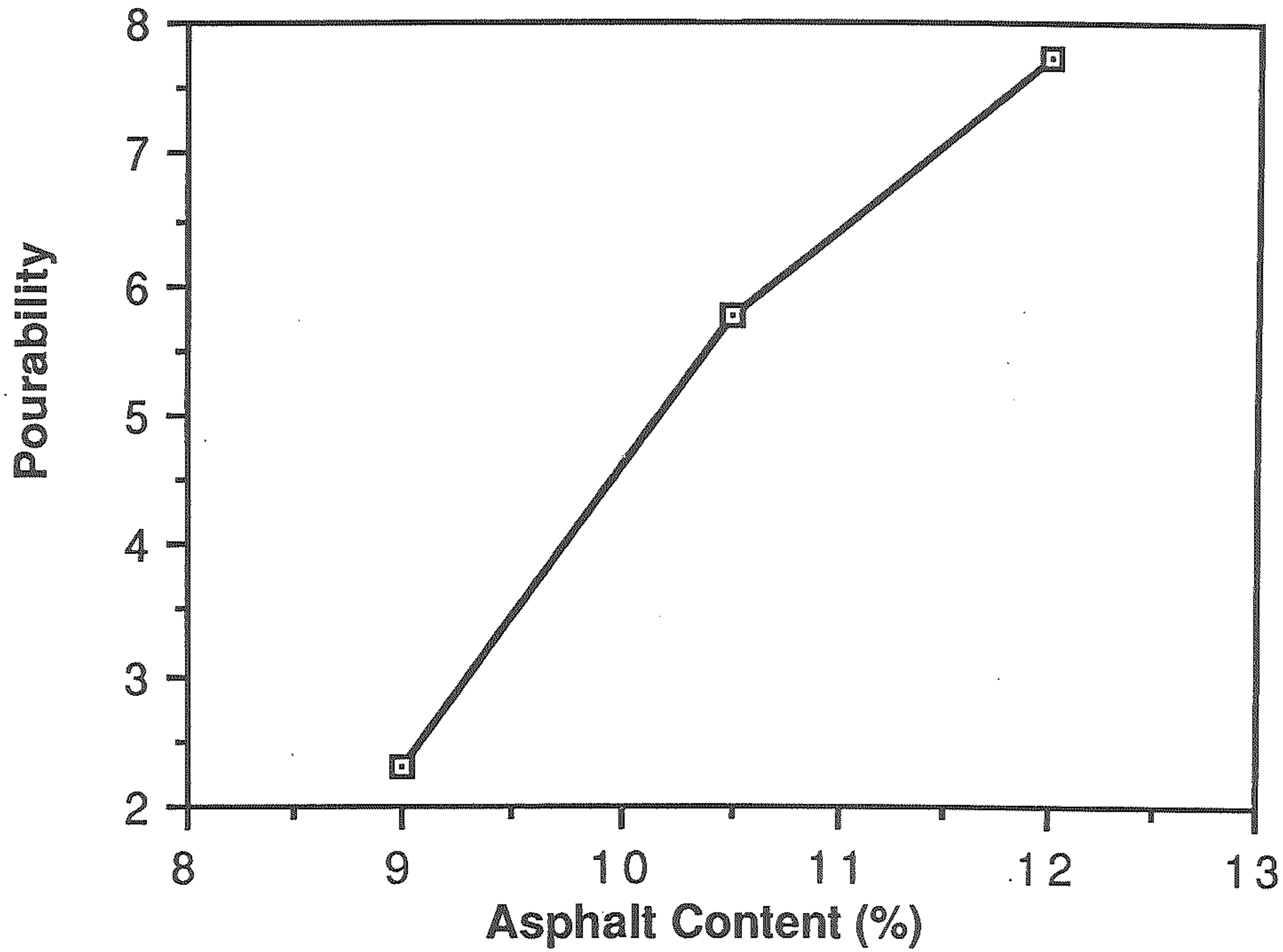

FIG 16. Pourability vs. asphalt content, average trend.

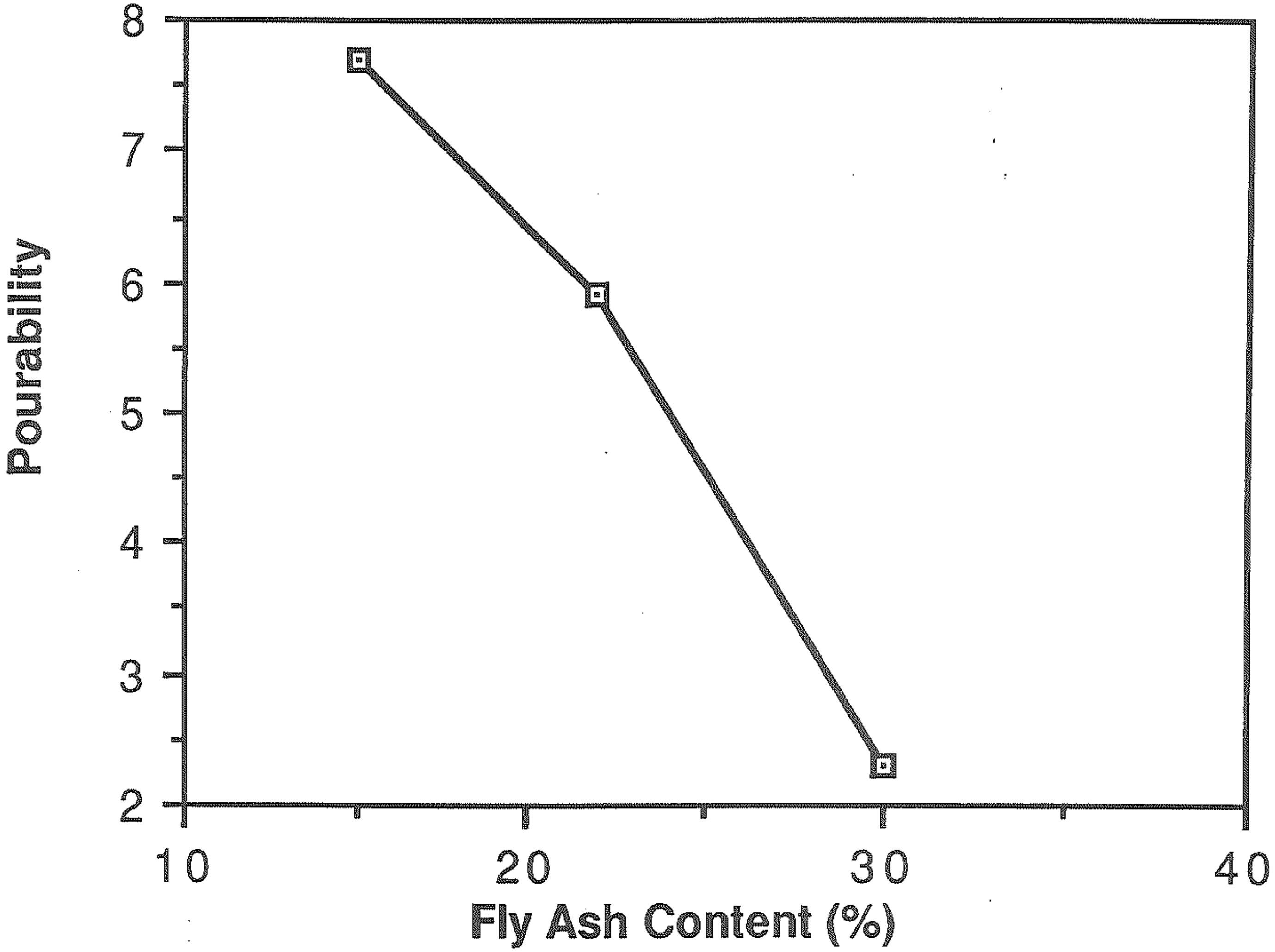

FIG 17. Pourability vs. fly ash content, average trend.

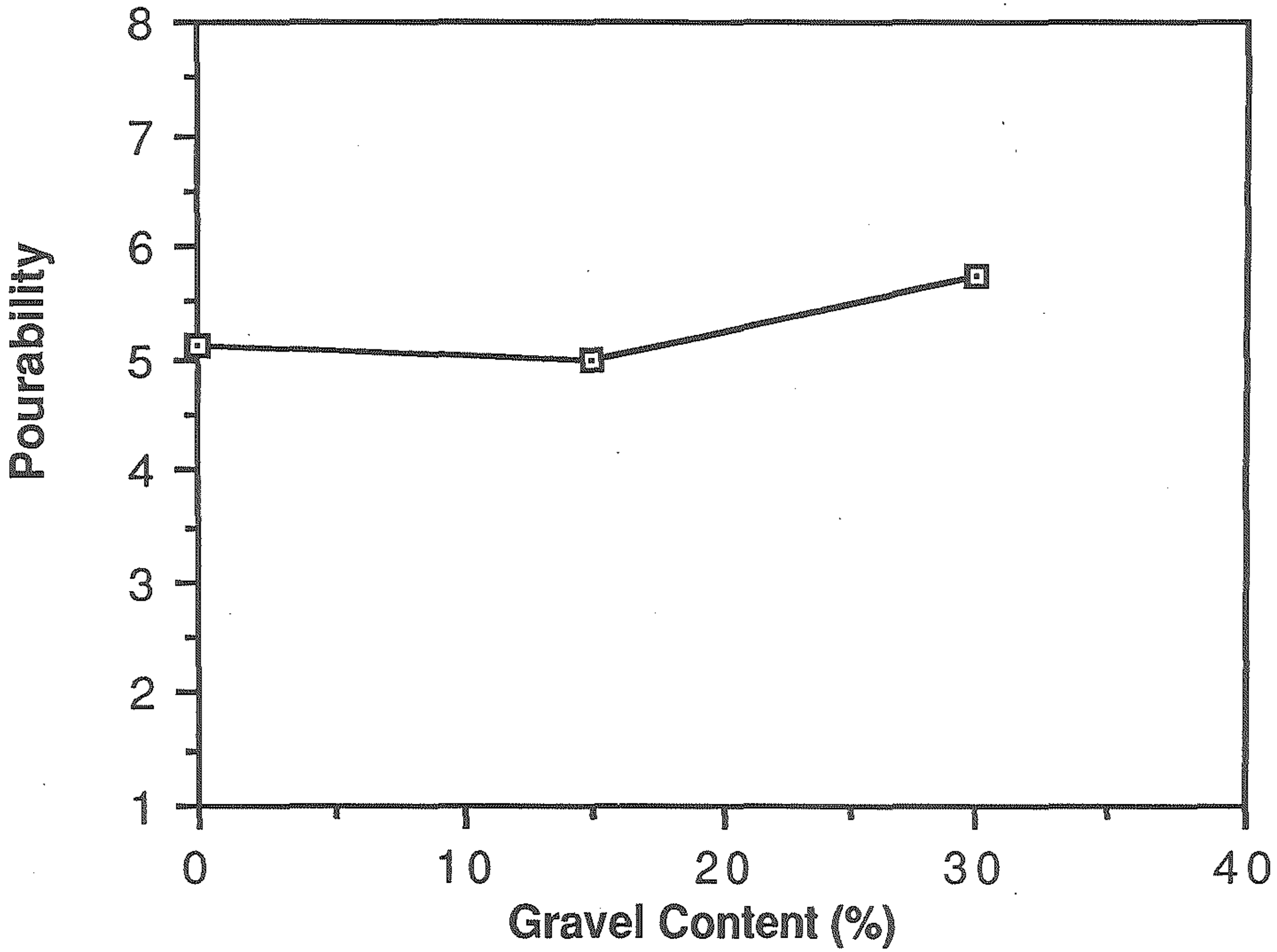

FIG 18. Pourability vs. gravel content, average trend.

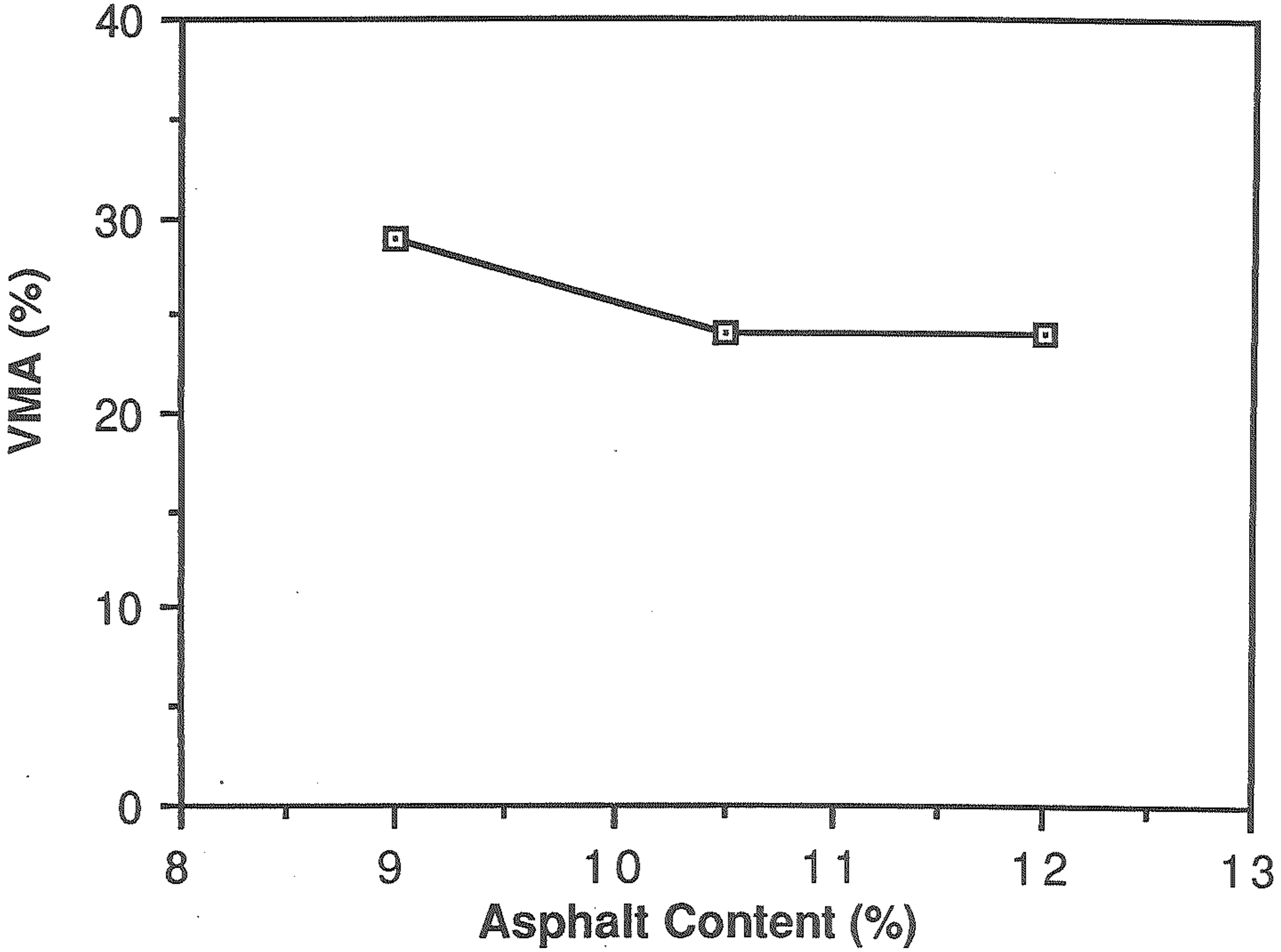

FIG 19. VMA vs. asphalt content, average trend.

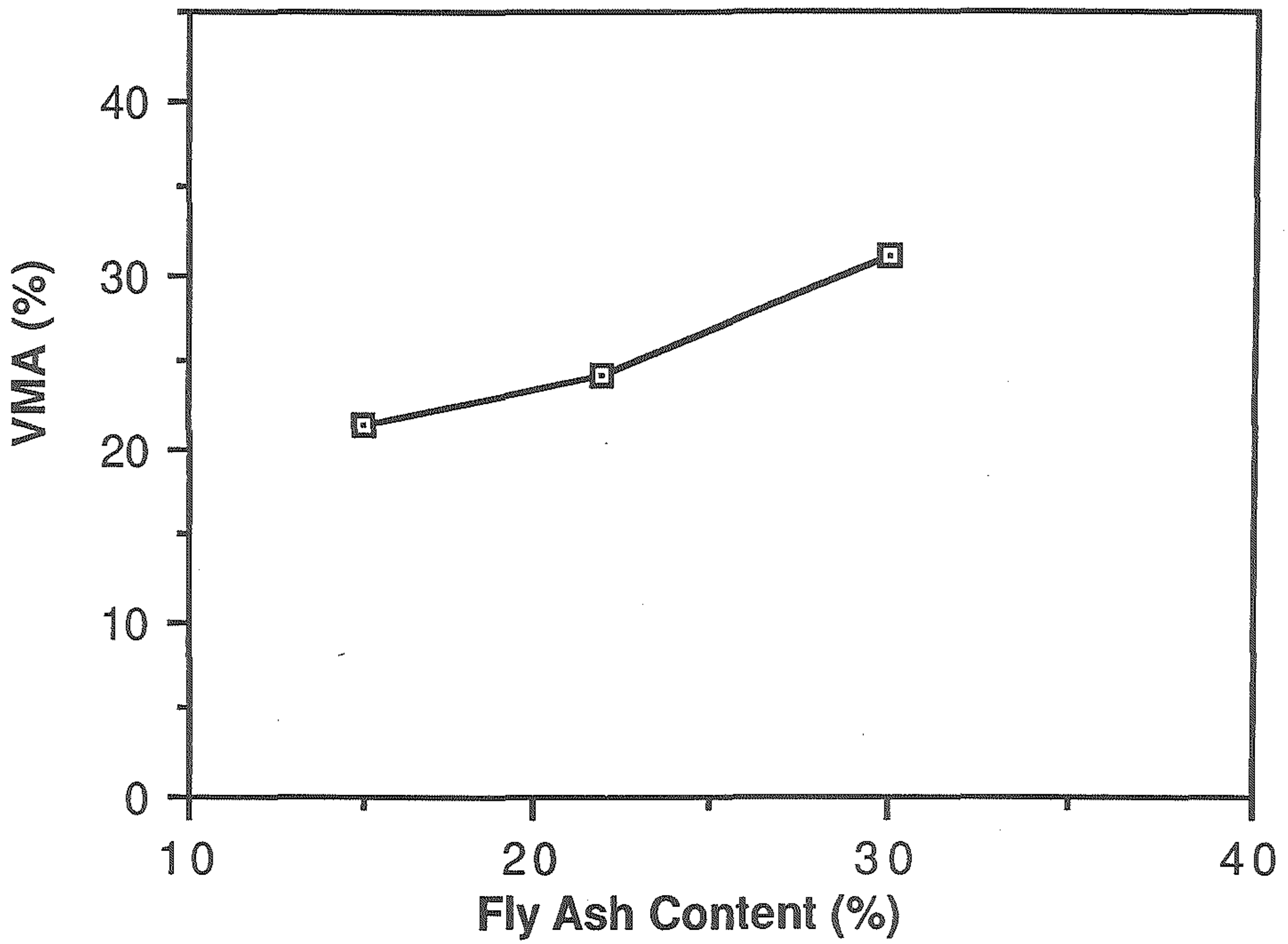

FIG 20. VMA vs. fly ash content, average trend.

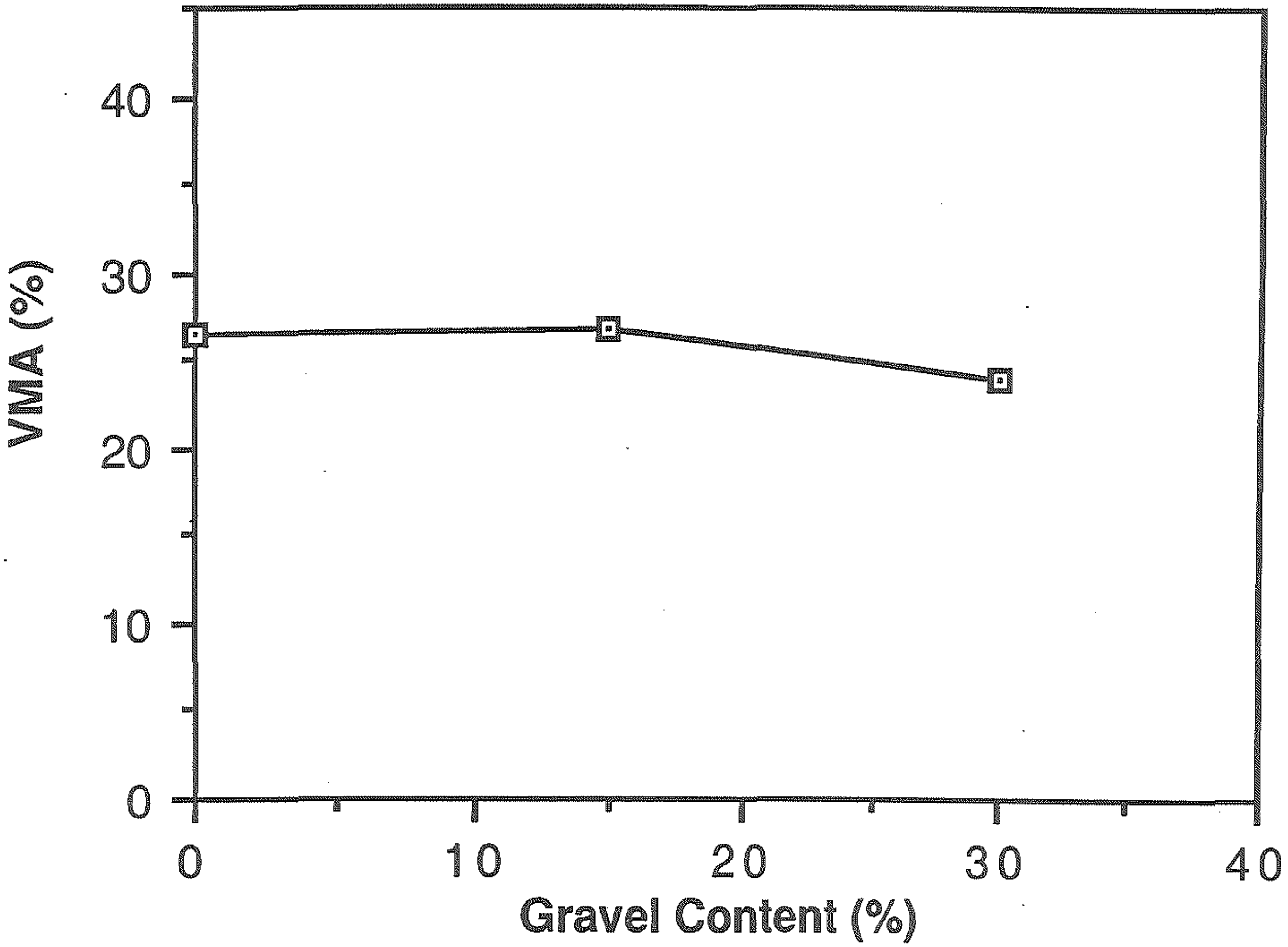

FIG 21. VMA vs. gravel content, average trend.

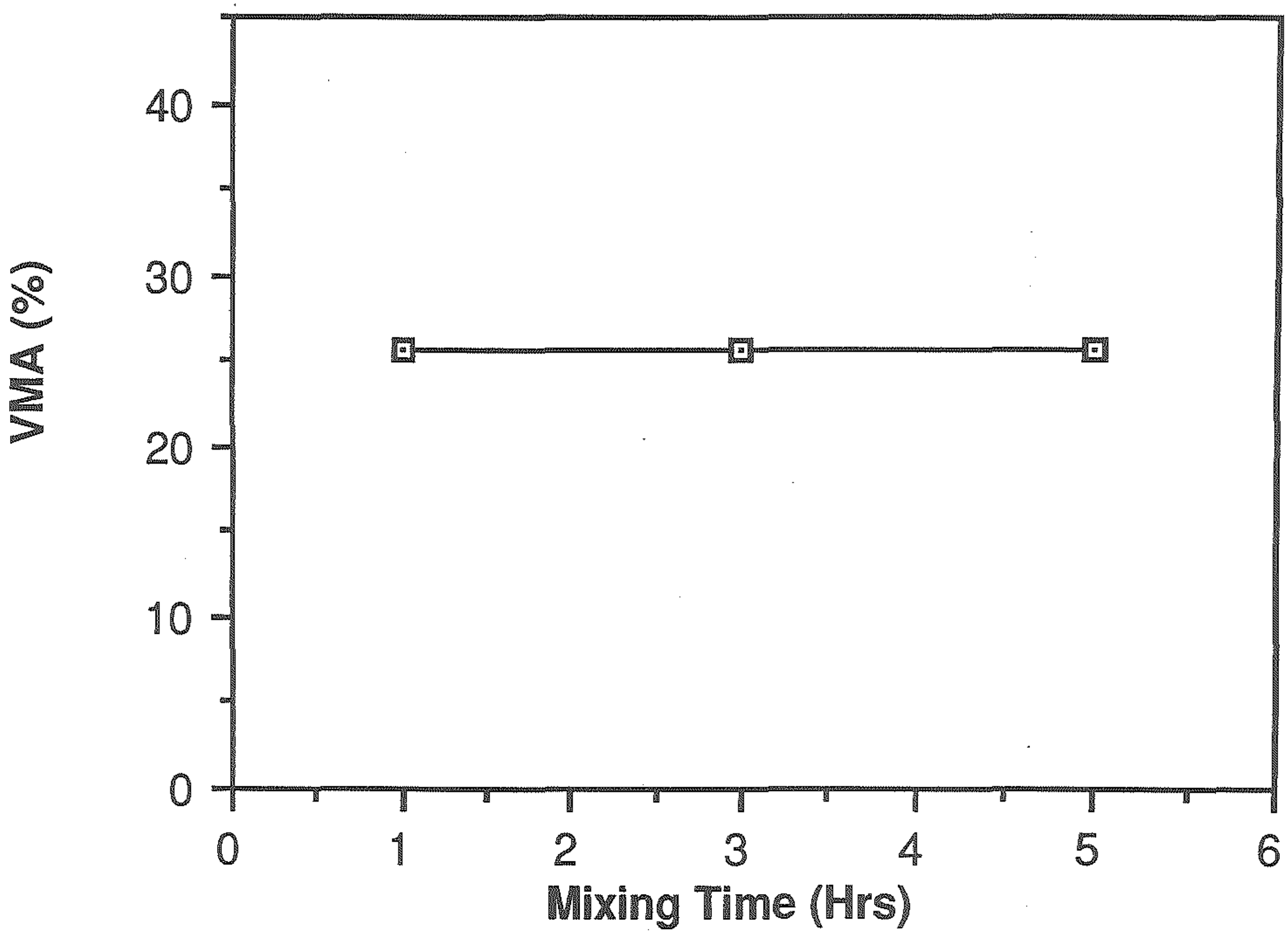

FIG 22. VMA vs. mixing time, average trend.

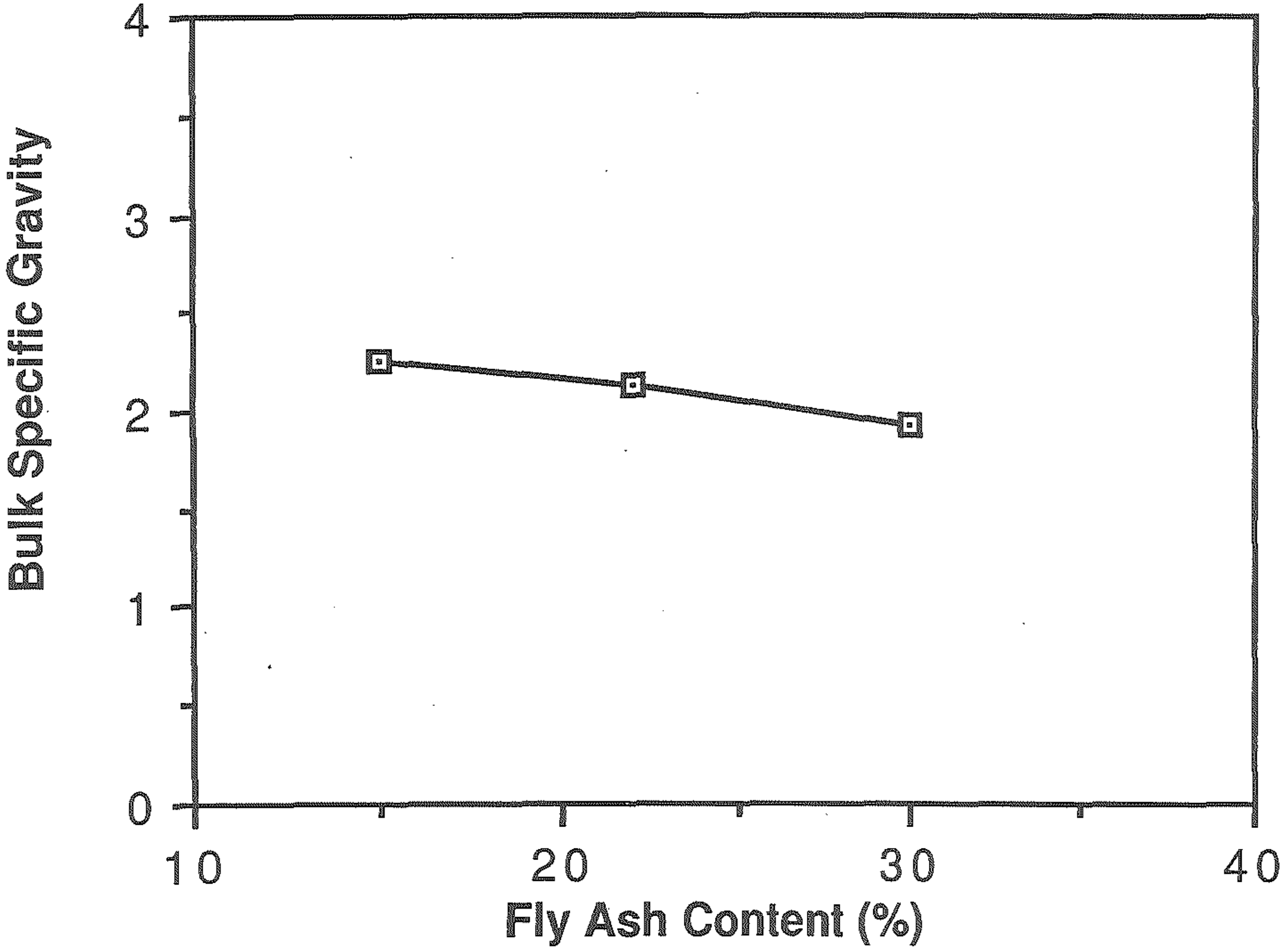

FIG 23. Bulk specific gravity vs. fly ash content, average trend.

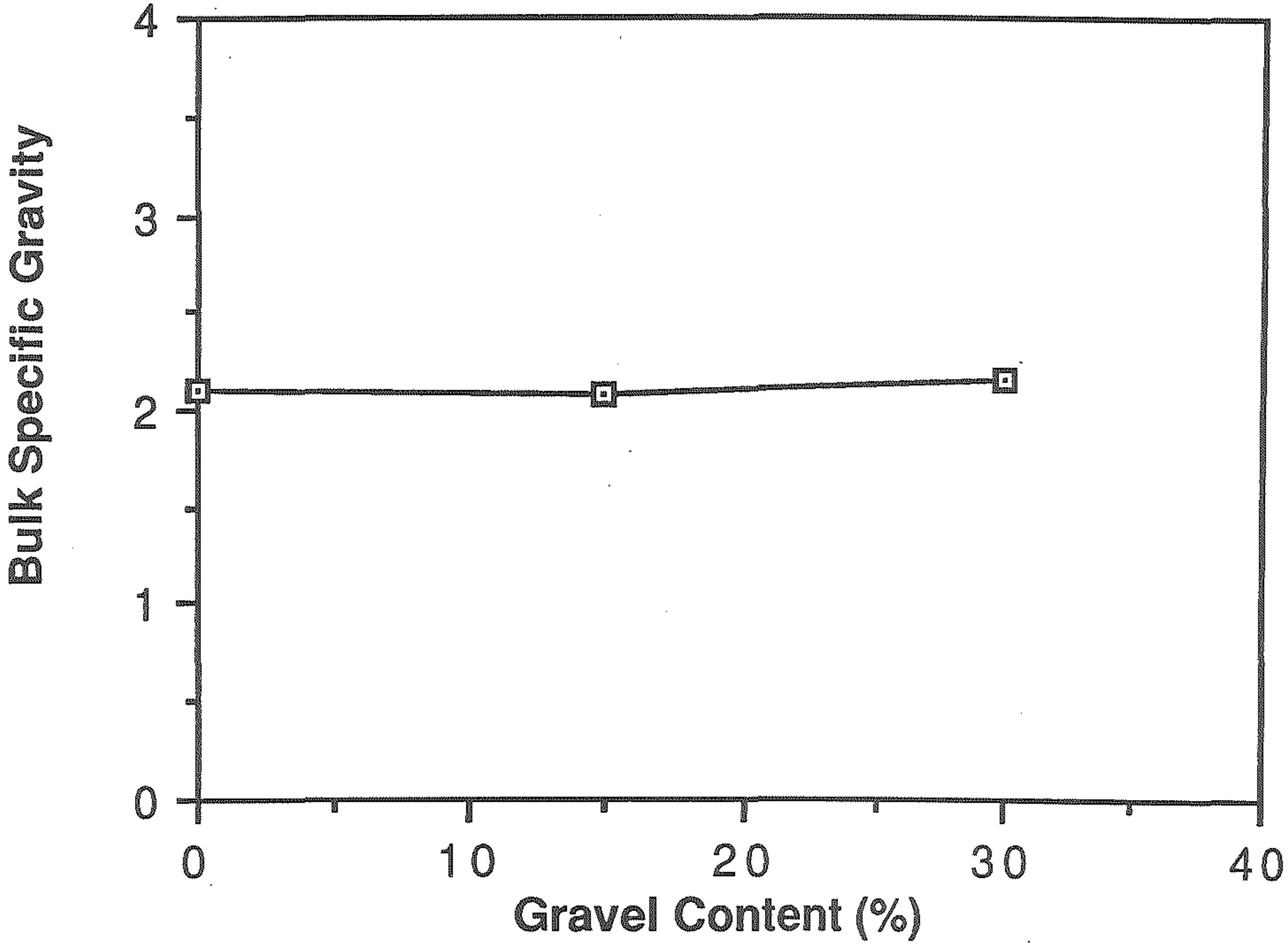

FIG 24. Bulk specific gravity vs. gravel content, average trend.

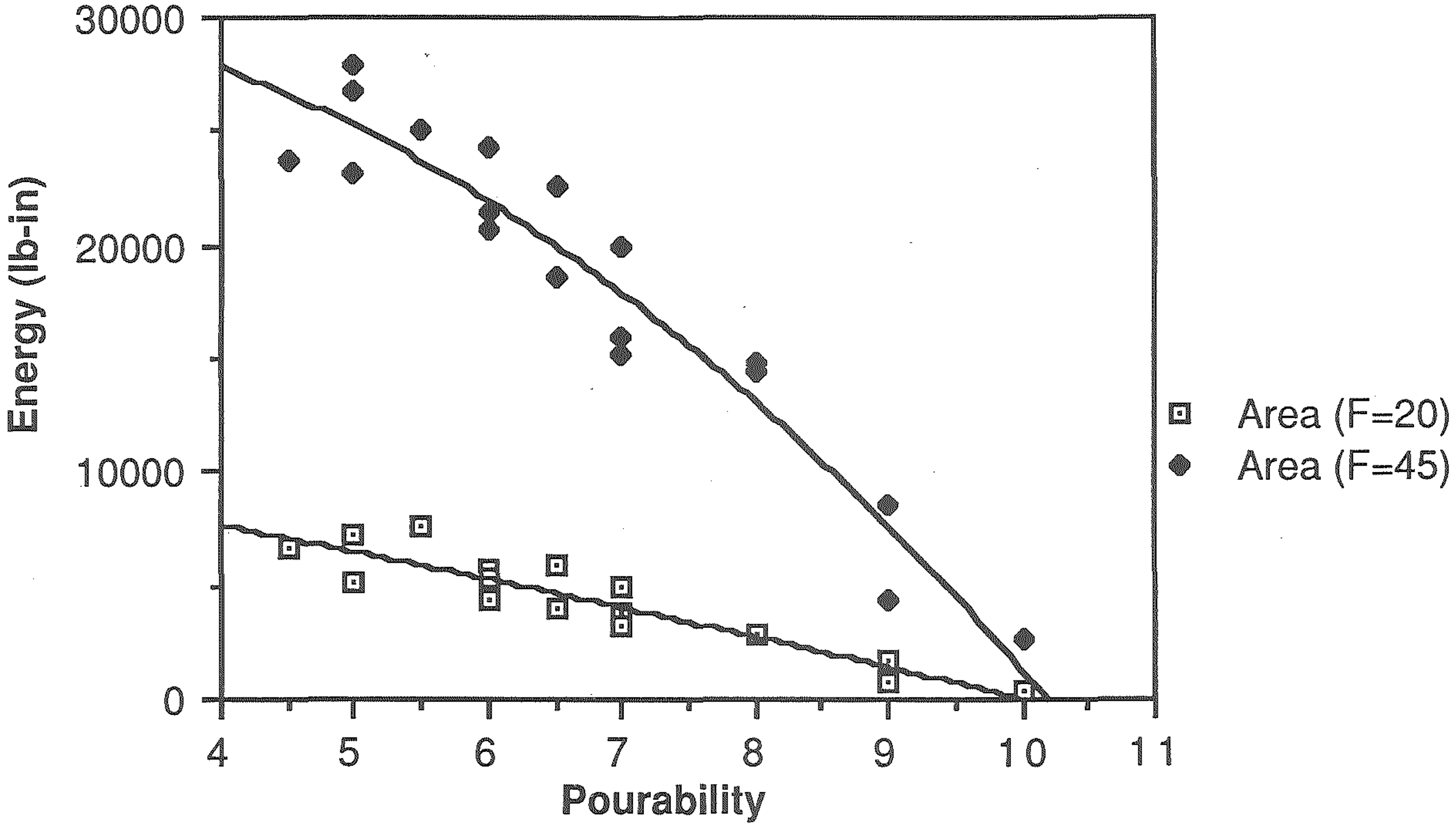

Fig 25. Energy or Area under the stability-flow curve vs. pourability