# ENGINEERING ECONOMY AND ENERGY CONSIDERATIONS

DESIGN AND CONSTRUCTION OF LIGHTWEIGHT ASPHALT CONCRETE MIXTURES

RESEARCH REPORT 214-26

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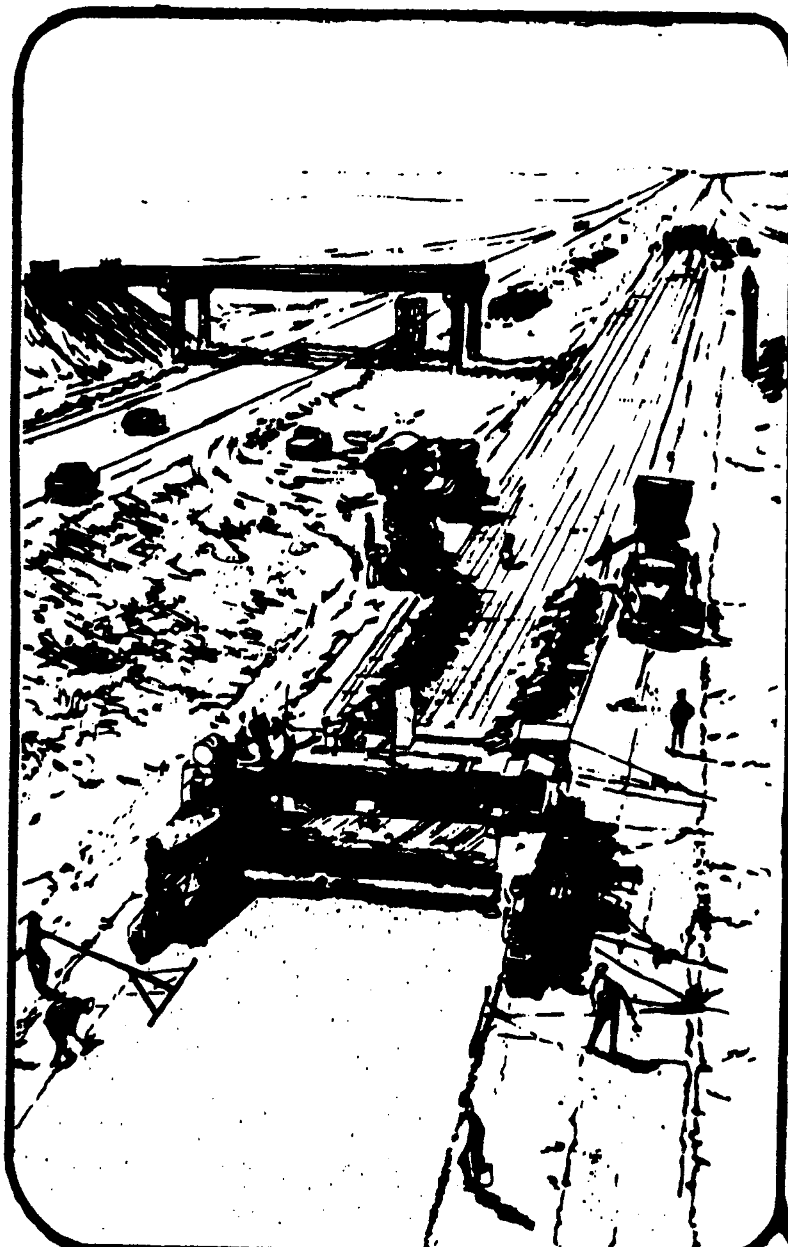

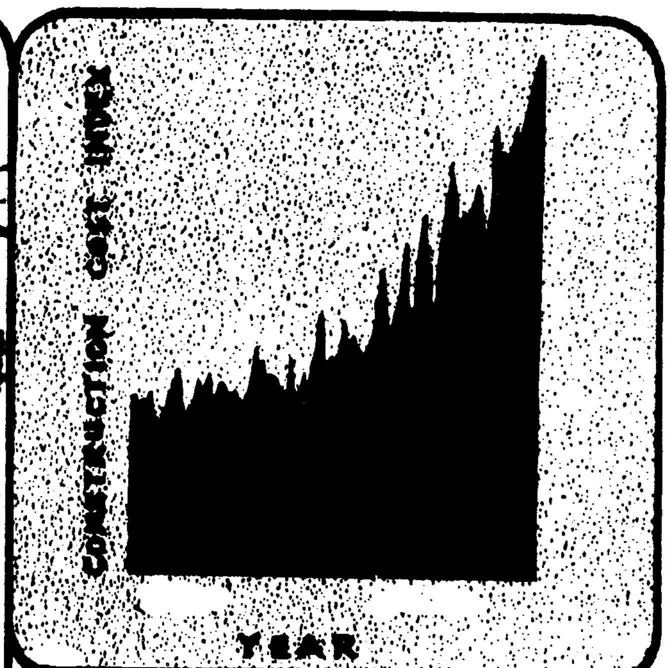


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"ENGINEERING, ECONOMY AND ENERGY CONSIDERATIONS IN DESIGN, CONSTRUCTION AND MATERIALS"

TEXAS STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

AND

TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M UNIVERSITY

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# DESIGN AND CONSTRUCTION
# OF
# LIGHTWEIGHT ASPHALT CONCRETE MIXTURES

by

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Report 214-26

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# INTRODUCTION

Demands for high polish value aggregates continue to increase as State and Federal Agencies work together to improve driving safety by upgrading the desirable surface properties of our nations highways. Lightweight aggregates produced from clays and shales by the rotary kiln process are suitable high polish aggregates and have been used extensively on Texas highways since 1961. Lightweight aggregates were initially used as cover stone for seal coats and surface treatments while their utilization in asphalt concrete hot mixes dates to 1965. Several thousand lane miles of lightweight hot mixes have been placed in service on Texas highways.

Lightweight asphalt concrete hot mixes are primarily used as overlays to restore skid resistance and secondarily to improve riding quality and improve the load carrying capability of the pavement structure. Construction and performance problems early in the life of facilities constructed with lightweight aggregate hot mixes have been noted. These problems have been defined by Texas State Department of Highways and Public Transportation (SDHPT) district personnel at a meeting held in Lufkin, Texas, on November 3, 1977 (1) and elsewhere (2, 3) as follows:

1. Slippage,
2. Potholing,
3. Raveling and
4. Radical failures during rainy cold weather.

Those attending the meeting recognized that many of the defined performance problems would be minimized or eliminated by improvements in design methods and/or construction practices. This report has been prepared in response to the recognized need for a document to define design and construction procedures which will improve the performance of lightweight asphalt concrete mixtures. The document is based on interviews and conversations with district and central office personnel of the SDHPT as well as research conducted at Texas A&M University (4-10). Resident engineers and inspection forces should find the guidelines contained within this report of interest.

## DESIGN CONSIDERATIONS

The engineer is concerned with pavement thickness design considerations as well as mixture design considerations when using asphalt concrete materials. Design considerations are discussed below.

### Pavement Thickness Design

From a pavement thickness design standpoint lightweight asphalt concrete can be expected to perform in a manner equivalent to normal weight hot mixtures. The load carrying and load distributing capability of lightweight and normal mixtures can be expected to be comparable. Thus, equivalent thickness should be used in new construction as well as in overlay designs.

The Texas Flexible Pavement Design System (FPS) should be used to determine overlay thickness. Other overlay thickness design procedures based on a suitable deflection procedure such as that recommended by The Asphalt Institute (11) or used by the California Division of Highways (12) can be used. The dynaflect is a suitable pavement deflection measuring instrument and should be utilized on all projects.

Overlay thickness designs based on available funds and the area of pavement surface to be overlaid should be avoided, as thin overlays often result which have early life performance problems. Slippage between the overlay and the old pavement surface is also a common form of distress when thin overlays are utilized. Thus, consideration should be given to establishing minimum overlay thickness for various traffic volumes, environmental conditions and type and condition of the old pavement. Until more rational minimums are established, it is recommended that asphalt concrete overlays have the minimum thickness as shown in Table 1. It should be recognized that overlays of the minimum thickness indicated in Table 1 will not stop reflection cracking (cracks propagating from the old pavement through the overlay) and may not be adequate to restore pavement smoothness. References 11, 12, 13, 14 and 15 should be reviewed if additional detail is desired on pavement overlay thickness design.

## Mixture Design

Asphalt concrete mixture design involves selection of the asphalt concrete, aggregates and proportioning of the mixture ingredients to achieve the desired stability, density and durability. Mixture design concepts associated with lightweight hot mixes are discussed below.

Selection of Asphalt. Item 300 of the Texas specifications (16) describes asphalt cements which are suitable for use in lightweight asphalt concrete mixtures. Historically AC-10 and AC-20 asphalt concrete have been used in Texas and have provided acceptable performance. The harder asphalt (AC-20) has been used in the warmer climates of the state and AC-10 in the colder climates. Report 214-27 (17) provides more detailed guidelines for selecting the grade of asphalt for various regions of the state. In areas where both AC-10 and AC-20 are acceptable, the engineer should consider the use of the softer of the two asphalts (AC-10). Improved durability can normally be obtained with the softer asphalt and minimum Hveem stability values are normally easily obtainable with lightweight aggregate hot mixes.

Selection of Aggregates. Currently there are two manufacturers of lightweight aggregates in Texas. One of these producers operates the plants, one plant located in Clodine, Texas, just west of Houston and one at Streetman, Texas, located on I-45 southeast of Dallas (Table 2). The other producer has a plant at Ranger, Texas, west of Fort Worth, Texas.

The production capacity of these three plants is in the order of 1.4 million cubic yards per year. About 30 percent of this production is used to produce high friction surfaces on Texas highways. Most of this lightweight material is furnished in a size meeting the requirements of Texas Specification Item 303, Grade 4, which grade is size predominately between the 1/2-inch and the No. 4 sieves. The aggregate particles are angular and rough textured and the internal make up of the particles is such as to furnish continuous microtexture as the particle gradually wears under the action of traffic.

The angular shape and rough surface texture of coarse lightweight aggregate particles affect facets of mix design, batching, and even placing of the final paving mixture. Additionally, the early performance of surfaces made with this material is indirectly affected. Under optimum design and construction conditions, textured aggregates will retain a heavy film of asphalt and this can contribute to delayed development of the desired (planned) level of friction. The design engineer should be aware of this delayed development of high friction and take the necessary precautions to offset this problem which may include removal of the surface asphalt film by scrubbing the surface of the pavement with an abrasive.

Physical properties of lightweight aggregates of interest to the engineer are shown in Table 3. Those properties vary depending upon the source of the raw material, treatment of the raw material prior to firing, length and temperatures of the burn, handling after burning, etc. Specifications for lightweight aggregates which are used in hot mix often contain the following requirements.

1. Dry loose unit weight - 35 minimum
2. Abrasion - 40 maximum (35 maximum for Texas)
3. Pressure slaking value - 6 maximum (4 maximum for Texas)
4. Polish value - 30, 33 or 35 minimum (Table 4) (18)
5. Freeze-thaw loss - 7 maximum for Texas

Because of economy and workability requirements most lightweight hot mixes contains lightweight aggregates as a portion of their coarse aggregate (plus No. 10) fraction only. Procedures and specifications have been developed by SDHPT to blend aggregates of different polish values, wear resistance and specific gravity. These procedures are given below.

<u>For Surface Course of Travel Lanes Only</u>

When shown on the plans, the coarse aggregate used in the surface or finish course must meet one of the following conditions:

Have a "polish value" of not less than the value shown on the plans. Where the coarse aggregates are supplied from two or more sources, the aggregate from each source shall meet the "polish value" shown on the plans prior to being combined with other aggregates. Polish values shall be determined in accordance with Test Method Tex-438-A, Part I or,

Have a "combined polish value" achieved by blending non-polishing aggregates with polishing aggregates in specific proportions as determined by Method "A" or Method "B" of Test Method Tex-438-A, Part II.

When the coarse aggregates are to be a blend of non-polishing aggregates with polishing aggregates to achieve a "combined polish value", the percent by volume of the non-polishing aggregate in the blend shall be that amount required to provide the polish value shown on the plans plus 2 when Method "A" is used. When Method "B" is used, the percent by volume of the non-polishing aggregate in the blend is determined by the formula based on the polish values of the aggregates to be blended. In addition, the non-polishing aggregate must be equal to, or greater, in resistance to wear than the polishing aggregate when tested in accordance with Test Method Tex-438-A, Part III.

However, in no case shall the non-polishing aggregate portion comprise less than 20 percent by volume of the total coarse aggregate. Further, a minimum percent by volume of non-polishing aggregates shall be required within critical size fractions as shown below for listed surface mixtures.

| | Type C | Type D | Type F |
|---|---|---|---|
| Retained #4 | 50% | | |
| Retained #4 | | 50% | |
| Passing #4, Retained #10 | | | 50% |

Specification compliance for proper proportioning of blended coarse aggregate shall be determined from representative samples obtained from the hot bins on conventional plants or from the cold feed immediately prior to entering the dryer-drum on the dryer-drum plants. Percent by volume may be determined by making a visual separation of the materials as outlined in Test Method Tex-413-A and converting weights to volumes by appropriate methods or by testing in accordance with Test Method Tex-200-F, Part III.

When coarse aggregates from any source include appreciable quantities of materials with substantially different mineralogy the more polish-resistant aggregates must be equal or greater in differential wear resistance than other aggregates from the source. The Engineer may establish this on the basis of satisfactory experience with the source or tests may be required in accordance with Test Method Tex-438-A, Part III.

Fine Aggregate. The fine aggregate shall be that part of the aggregate passing the No. 10 sieve of uniform quality throughout the hereinafter specified or otherwise shown on the plans.

Fine aggregate shall consist of durable particles, free from injurious foreign matter. The plasticity index of that part of fine aggregate passing the No. 40 sieve shall be not more than 6 when tested in accordance with Test Method Tex-106-E. Fine aggregate from each source shall meet plasticity requirements.

Gradations of aggregates used in lightweight hot mixes should conform to standard Type D or Type C, Item 340 (19). It should be recognized that these gradations are on a volume basis and not a weight basis.

Proportioning of Mixtures. Proportions of lightweight asphalt concrete mixture designs must be established on volume concepts. Volumetric design procedures have been developed and are in use across the state. Appendix A contains the method recommended for use by the Texas SDHPT. It should be recognized that all hot mix designs are volumetric designs but for convenience the engineer performs calculations on a weight basis. Significant errors are not introduced provided the specific gravities of all aggregate fractions are nearly identical. The engineer is encouraged to fully understand weight-volume calculations prior to designing lightweight asphalt concrete mixtures.

Hveem stability and laboratory compacted density requirements have been found to be satisfactory for establishing asphalt cement contents in lightweight mixes. Test methods identical to those used for normal weight mixes are acceptable (Appendix A).

## CONSTRUCTION CONSIDERATIONS

The use of lightweight aggregates in hot mixes introduces several unique construction features that the engineer must consider if a long service life is to be obtained. These construction considerations are discussed below in terms of plant, transportation and laydown and compaction operations.

### Plant Considerations

There are roughly 4,300 hot mix plants in the United States engaged in the production of hot asphalt-aggregate mixtures. The large majority of these plants are the weight batch type; however, the new plants being purchased today are mostly the drum dryer continuous mix type. The use of this newer type of plant in conjunction with volumetric mixture design method previously outlined should simplify mixture production and result in a smooth operation.

For contractors who use the weight batch plants, volume design will have to be presented on a weight basis for batching purposes. However, mixture design specification compliance should be on a volume basis. In reality, the cold feed of a weight batch plant is generally operated on a volume basis just as it is in a continuous mix type of plant.

Contractor and State personnel are generally aware of the differences in hot mix operations involving the use of lightweight aggregates: however, a review of these differences and suggestions for possible modifications of general practice appears to be in order and is given in the following paragraphs.

Because lightweight aggregates have water absorption capacities ranging from 10 to 25 percent and because the water release rate is often lower for such materials, it is practically impossible to remove all absorbed water in the normal operation of a regular hot-mix plant. Additionally, the absorbed water problem is usually compounded by the presence of free water on the aggregate particles. In the event that poor drying conditions prevail, further complications will naturally be imposed.

Aggregate Drying. The plant operator has several alternatives for improving aggregate drying including:

a) Changing the rate at which the material passes through the dryer.

b) Drying and stockpiling material for rerunning.

c) Lowering the exit temperature of the dryer or

d) Raising the exit temperature of the dryer.

Drying Rate. Let us pause now and direct our attention to the drying efficiency that would be brought about by changing (reducing) the rate at which the material passes through the dryer. This method is often effective but production is naturally reduced. Not only is production reduced but also plant down time is necessary to change the rpm and slope of the dryer. A change back to normal operation would then require readjustment of the dryer and another time loss event.

Predrying. Drying and stockpiling material for early morning operation is a workable solution and this approach has been successfully practiced. Let us assume a job with stockpiles of wet aggregates and poor drying conditions--low temperature and high humidity. Let us further assume that moisture measurements on the lightweight coarse material indicate 18 percent total water and a similar check on the fine material show 6 percent water. These are not unusual values, in fact, a moisture content in the 25 percent range for certain lightweight materials is not uncommon. Under such circumstances predrying of the lightweight material will probably solve the moisture problem. Complete drying is not required. With wet lightweight in the 15 to 20 percent moisture content range drying back to 3 to 6 percent moisture would be satisfactory. Predried material should be stockpiled separately at least one day before it is needed and used only as necessary to produce the desired end product. This will usually mean using all predried lightweight when the plant is "kicked off" in the morning and then as the air temperature rises and the humidity drops, less and less predried material goes to the cold bins. By noon or before it may be feasible to go entirely to the wet aggregate stockpile. Any slack time in the plant operation should be used to stockpile more predried lightweight for the next morning. Predried material should be covered in the event of rain.

It is not advisable to cover predried material to protect it from absorbing water from the air. Lightweight aggregate that leaves the dryer with, say 3 to 6 percent moisture will continue to lose some moisture if the stockpile is left uncovered. Covering the hot material will cause condensation on the cover and this water be returned to the aggregate. If the aggregate is not covered, moisture would leave the as water vapor.

An efficient and workable program of predrying requires planning and good judgment on the part of the plant superintendent. It is, nevertheless, an effective partial solution to the successful placing of lightweight hot-mix.

Lower the Exit Temperature of the Dryer. Although some plant operate with dual dryers arranged in series, most hot mix plants consist of a single dryer that operates on a fixed slope, flight design, and rotational speed. During normal operations material passing through the plant does so on a fixed time schedule and this means that drying is controlled primarily by drum gas flow rate and dryer temperature.

Drying of very wet materials may cause delayed moisture release which may in turn result in slumping of the mixture in the haul units and may also cause fat spots on the road. Under some circumstances lowering the dryer temperature rather than raising it will eliminate these problems. Raising the dryer temperature often aggravates the problem. An increase in drum gas velocity associated with lowering of the temperature will also be found helpful. A change in flight design may also be in order.

Raise Dryer Temperature. The natural tendency is to raise the dryer temperature and frequently this has been found effective; however, for most lightweight aggregates with high stockpile moisture contents this will not solve the problem. The release of water from the lightweight material may be too slow and as a result the mix is dropped into the haul truck while water is still being evaporated from the pore structure of the coarse material. This evaporation of water cools the mix at a rate of 40°F for each percent of water evaporated. Since no heat is added to the system after it leaves the dryer, the mix as it drops into the haul truck may be 40 to 90°F cooler than the aggregate leaving the dryer because of evaporative cooling.

Field observations indicate the aggregate at the dryer may be at 350°F while the mix temperature as it drops into the haul unit may be only 260°F. Thus, the evaporative cooling during hot storage and mixing may have a pronounced effect on placing operations.

With this approach to the problem, the question then is--"Can we live with this""--and we may very well be able to do so. More specific answers will be supplied later in this discussion.

Additional Considerations - Evaporative Cooling, Water Release, Etc.

One additional alternative is that of closing the job and waiting for improved operating conditions. Generally, this is a costly choice and should be avoided if at all practical.

The experienced plant operator is aware of the various approaches to problem drying that have been discussed to this point, He may not, however, be aware of the rates and magnitudes of limiting factors affecting the successful placing of hot mix containing lightweight aggregates.

## Transportation

The transportation of lightweight aggregate hot mix asphalt concrete presents no special problems provided the aggregates are dry. For long hauls on cool days covering of the mixture is suggested and/or higher mixing temperature may be required.

Average temperature drop of 10 to 15°F due to heat losses of water-free hot mix in the haul unit and laydown machine are commonly assumed for the normal operation. Although less heat is carried out in a given volume of lightweight material the rate of cooling will normally be less than for an equal volume (truckload) of regular mix.

The presence of water in the aggregate can, however, present special problems. Field evidence exists which indicates that wet aggregate within hot asphalt concrete mixtures continues to lose water by evaporation. This water vapor may condense and collect at localized places within the load or the bed of the truck. At the placing site the asphalt concrete may be extremely fluid and will flush or bleed in the localized area of moisture collection and release. Evidence of this type of distress is apparent in the form of pairs of flushed areas one on either side of the center line of a given pass of the laydown machine and sequenced with each load of material placed. A regular pattern will prevail as long as the problem persists. A great deal of excess moisture in the mixture will produce an asphalt concrete that will readily flow from the haul unit. Difficulty is encountered during the placing and compaction of this "6-inch slump" asphalt concrete.

## Laydown and Compaction

Problems with laydown and compaction operations may be functions of mixture properties, but often they are temperature related. Problems with harsh or tender mixtures (associated with aggregate gradation, shape and surface texture and to certain asphalt setting properties) may be expected with lightweight hot mixes but these problems are relatively few if one follows the materials and construction control specifications presently in use. Consequently, the discussion will move directly to mix temperature as it relates to laydown and compaction operations.

Background on Cessation Requirements. Cessation requirements for rolling hot mix have been developed by a number of agencies and are given in references 20-25. These requirements are based on a knowledge of the following:

1. The rate at which the mat cools,
2. Establishment of a "reasonable time" for applying breakdown rolling and
3. The temperature below which breakdown rolling is not very effective in producing mat density.

The National Asphalt Pavement Association's Quality Improvement Committee through a series of questionnaires, meetings and a review of the literature has established that breakdown rolling below about 175°F for most dense mixtures produces limited compaction. This same committee suggested that 8 minutes is the minimum time required for passes of the breakdown rolling for thin lifts and 15 minutes is the minimum for thicker lifts of asphalt concrete. These time restrictions thus affect the paver speed as well as plant production rates and associated transportation operations. For roller speeds of 3.5 miles per hour and an eight-minute roller time, one roller will limit the paver to a speed of about 30 feet per minute while two rollers will allow paver speeds up to 55 feet per minute. For fifteen-minute roller times the respective paving speeds will be 30 and about 60 feet per minute. Eight and fifteen minute available compaction times will be used in the following discussion together with the 175°F temperature below which breakdown rolling is no longer very effective.

Mat cooling curves have been simulated by mathematical models and computer solutions have been developed for both normal weight (22, 24) and lightweight hot mixes (21). Field data have verified these solutions for asphalt concrete mixtures made with normal weight aggregates. Field correlations have not been established for lightweight mixtures.

Cooling curves for lightweight aggregates were generated from a computer program developed by Corlew and Dickson (22) and modified by the Texas Transportation Institute (21). Cooling curves shown in Appendix B were developed for base temperatures of 30, 50 and 70°F and mat temperatures of 200, 230, 260, 290 and 320°F. A wind velocity of 10 knots* and an elevation of approximately 500 feet were selected for all solutions. Air temperature and solar flux were selected in reference 1. Thermal properties for lightweight aggregate hot mixes as compared to normal weight hot mixes are listed below.

| | Lightweight Hot Mixes | Normal Weight Hot Mixes |
|---|---|---|
| Thermal conductivity, Btu, $hr^{-1}$, $ft^{-1}$, $F^{-1}$ | 0.35 | 0.70 |
| Thermal diffusivity $ft^2$, $hr^{-1}$ | 0.0227 | 0.0138 |
| Specific heat, Btu, $lb^{-1}$, $ft^{-1}$ | 0.22 | 0.22 |

A wind velocity change of plus or minus 10 knots can alter the mat cooling time plus or minus about 2 minutes. The temperature noted on

*Knot (nautical miles per hour) is the unit commonly used for wind velocity. 1 nautical mile - 1.15 statute miles.

these figures represents that expected at the center of the placed mat.

Figure 1 summarizes the data presented in Appendix B by shown the time to cool to 175°F for mat thicknesses of 1, 1 1/2, and 2-inches, base temperatures of 30, 50 and 70 and a range of laydown temperatures. The relative importance of mat thickness, base temperature and laydown temperatures can be illustrated by use of these figures. For example, a change at laydown temperature of a 1 1/2-inch mat from 260 to 290°F placed on a 50°F base will change the cooling time from 17 minutes to 22 minutes while a change in base temperatures from 30 to 70°F for 1 1/2-inch mat placed at 260°F will change the cooling time from 15 minutes to 20 minutes.

The importance of mat thickness on cooling time is the single most important factor as illustrated in the following example. Assuming the laydown temperature of 220°F and a 50°F base temperature, the cooling time for a 1-inch mat is about 4.5 minutes, for a 1 1/2-inch mat 10 minutes and a 2-inch mat 17.5 minutes.

It should be emphasized that the treatment of rate at which these mats cool, assumes that the hot mix is essentially dry when it is placed and that cooling is caused principally by conduction and radiation. The importance of water evaporation on cooling rate is discussed below. To this point it has been assumed that the lightweight aggregate mixes in question were essentially water free (less than one percent moisture) when they were dropped into the haul units. And this may very well be the case in the hot summer time when the stockpile moisture contents of all aggregates are low and the drying conditions are good.

Such is not usually the case in late fall, during winter and in early spring. Stockpiles are usually wet and drying conditions are generally poor.

The paving mixture may contain 3 to 6 percent moisture as it is dropped into the haul unit and the mix temperature may not be above 250°F in spite of much higher dryer exit temperature, possible as high as 375°F. As discussed previously delayed evaportation of water is the cause of this problem. The dryer is capable of removing most of the free water on the aggregate, but some of the absorbed water is left in the lightweight aggregate to be driven off by the heat (sometimes referred to as "heat capacity") carried out of the dryer by both the coarse and the fine aggregates.

The actual amount of water that a mix will release in a given situation is difficult to estimate. Nevertheless, any evaporation which takes place after the aggregate leaves the dryer and before the mix is finally compacted in the field lowers the temperature and increases the mass viscosity of the mixture. At the same time a limited amount of moisture in the mat may act as a compaction aid! However, an excess of moisture in the finished mat is undesirable, since experience has shown that excess moisture may contribute to early structural distress in the form of tenderness, spot-to-spot mat distortion or disintegration.

Cessation Requirements for Lightweight Asphalt Concrete. It is apparent that some moisture will be lost from the aggregate after "drying" and prior to mixing and after mixing and prior to completion of breakdown rolling. Thus, the influence of moisture on cooling should be included in cessation requirements. The amount of moisture, however, has not be established by field work. Under wet cool conditions a first estimate would be, for mixes with 2 to 4 percent moisture at the time the mix is dropped in the truck, to lose about half of this moisture. Thus, the temperature loss of asphalt concrete during transport, laydown and compaction operations could amount to 80 to 90°F due to evaporative cooling.

In most cases of high moisture contents and poor drying conditions considerable evaporative cooling of the aggregate and some cooling of the mix will have occurred between the dryer and discharge to the haul unit - this in addition to the evaporative cooling under discussion. However, thermal monitoring of the mix as it is discharged into the haul is standard practice, hence the treatment of heat losses from this point through breakdown rolling is of importance.

With these data in mind cessation requirements or the conditions under which mixtures can have a reasonable degree of being successfully placed and adequately densified in the field have been established. Figures 2 through 7 graphically present these requirements. Figures 2, 3, and 4 were established for 15 minutes of available compaction time which allows paver speeds to 30 feet per minute if one breakdown roller is used and 60 feet per minute if two breakdown roller are used. Figures 5, 6 and 7 were established for 8 minutes of available compaction time, the minimum time required for breakdown with one roller. This requirement of eight-minute roller time will limit the paver speed to 30 and 55 feet per minute for one and two rollers respectively.

A specific example will illustrate the usefulness of Figures 2 to 7. Assuming 8-minute cooling time and a 1 1/2-inch mat thickness as typical of many paving operations utilizing dense graded lightweight aggregate hot mixes. Figure 6 would be selected. Assuming no moisture is lost from the time the aggregate leaves the dryer to a point in time after breakdown compaction beings, a 210°F temperature is required on a 50°F base. Similarly, if the moisture content of this mix dropped one percentage point during this same period, a temperature of 250°F would be required, and for 2 percentage points moisture loss a temperature of 295°F would be required, both referenced at the exit of the pugmill. As previously discussed for high moisture content aggregates, it would be difficult to reach this required 295°F temperature due to evaporative cooling during hot aggregate handling operations and the normal 10 to 15°F temperature loss experienced during transportation and laydown. Both of these factors may require the 295°F temperature to be achieved by supplying a hot aggregate as it leaves the dryer at a temperature in the neighborhood of 400°F which may be considered impractical from an economic standpoint. Figure 8 has been prepared to compare cessation requirements for normal and lightweight asphalt concrete mixtures. Lightweight mixtures without moisture cool at a lower rate than normal weight mixes. Thus, if the lightweight aggregate is thoroughly dried and moisture loss in not occurring lower laydown temperatures can be tolerated than with normal weight mixes. However, if moisture loss does occur much higher laydown temperatures will be required.

Use of Silicone. Extensive use of silicone in asphalt cement for eliminating foaming is well documented. Within the past about 20 years silicone has been widely used to reduce tearing or pulling of the mat behind the laydown machine. Silicone has also been found useful in improving the release of moisture from hot mix. It is in this area of use that contractors may wish to explore the advantages of using silicone in asphalt cement programmed for lightweight aggregate mixtures.

According to NAPA (26) the most widely used silicone is Dow Corning 200 Fluid (DC-200) which technically is a dimethyl siloxane polymer.

The effect of moisture release from the aggregate in a hot asphalt concrete mixture is to create steam which forms asphalt bubbles as the water vapor leaves the asphalt coated aggregate. These bubbles are trapped in the mix and the load of paving mixture may become fluid. The addition of 2 parts per million of the silicone fluid (about 2 ounces per 5,000 gallons of asphalt cement) will depress the formation of these bubbles and the mix will not slump (become fluid) in the haul unit nor will the mix tear or pull behind the laydown machine. Additionally, it has been found that silicone treatment of asphalt cement reduces the rate of hardening during hot storage. Hot storage or the use of surge tanks is widely practiced, particularly at fixed plants in urban areas.

The use or more than about 2 ounces of DC-200 in 5,000 gallons of asphalt cement appears to serve no useful purpose and in fact under certain circumstances a large dose (10 ounces in 5,000 gallons) has been found to cause some mixes to appear tender when compacted, all other factors fixed.

The cost of treating asphalt with DC-200 at the above specified rate is minimal, amounting to less than one half cent per tone of mix.

Numerous studies on the effect of low level DC-200 treatment of asphalt cement have shown no measurable detrimental effects on the properities of the cement or the mixtures in which the treated cements were used. The beneficial effects have been outstanding. It is therefore recommended that DC-200 or other suitable material be used at all times in lightweight aggregate mixtures where moisture in the mix is expected to be a problem.

## PERFORMANCE

Based on conversations with the SDHPT Austin office and District personnel, materials suppliers and personal observations in the field, problems have developed on certain jobs where lightweight aggregates have been used in plant mixes. Some of these have been quite costly. In contrast, problems have not developed in other jobs of similar design which utilized aggregates from the same source. It would be quite difficult to determine the magnitude of factors that may have contributed to the success or the failure of these different jobs. Furthermore, it is not the purpose of this discussion to point an accusing finger at anyone. But rather, it is hoped that a discussion covering several of the possible reasons for pavement distress will be useful to the Materials Supplier, Design Engineer, the State Inspector and the Contractor and will assist in improving the success ratio of similar jobs now under contract or planned for the future. The potential for improved cost-benefit ratio is great.

### Traffic, Wear and Reduced Skid Numbers

The structural design of Texas highways is normally based on equivalent 18-kip axle loads for an estimated life of say, fifteen years. On the other hand, design for the surface properties of Texas pavements is usually based on average daily traffic on a given facility independent of number of lanes or percent of trucks. A more realistic estimate of traffic effects on the surface properties of each lane of the highway should involve a correction for added wear and increased rate of polishing caused by trucks. The authors are not aware of any published data which give the needed equivalency. Estimates vary from 25 to 50, that is, one 18-wheeler is equivalent to 25 to 50 passenger vehicles. Even at an equivalency of 25 and an assumed 10 percent trucks, the corrected ADT per lane expressed in terms of passenger vehicles only would be increased three-fold! In addition, selected segments of some Interstate Highways carry 40 percent or more trucks in a given lane.

Slippage Problems

As a general rule, surface layers with a polish value requirement, placed as part of new construction or for friction improvement on an existing highway, are quite thin ranging from 3/4-inch to 1 1/2-inch in thickness.

The magnitude of the traffic-induced horizontal shear force at the interface between the surface layer and the substrate or underlying pavement is a function of externally applied shear force and the depth of the interface below the pavement surface. All other factors considered constant, the force transmitted at the interface between the overlay and the substrate is related directly to frictional properties of the overlay. One might then say that for an overlay of given thickness, as the pavement friction increases, so must the bond strength at the interface.

Possible, there should be special provisions in specifications and construction procedures to assure adequate bond thin high friction overlays. The need for such a requirement is not as critical for dense mixes as it is for OGFC.

Just as there are few points of contact within the mat of an OGFC, there are even fewer at the interface with the substrate asphalt drain down, if it occurs, will serve to improve this bond but in many cases this drain down in minimal or nonexistent. The result is a thin harsh mix resting on a relatively smooth substrate and subjected to very large horizontal shear forces. It is not at all suprising that there are reported instances of debonding, with some of these taking place at an alarming rate!

One answer is a rough textured substrate that will provide a mechanical interlock between the layers and enhance adhesion via increased area of contact between the asphalt coated aggregate particles of the hot mix and the substrate. A flush seal with cover aggregate in the form of crusher fines might offer a solution and in certain cases a heavy tack coat could be expected to serve adequately. Weather conditions permitting, emulsified asphalt should be used for interlayer bonding, HVRS-90 or CRS-2h is suggested. The usual practice is to dilute the emulsion with an equal volume of water and apply the mixture at a rate of about 0.1 gals/sq/yd. Road surface conditions and weather may create a need to apply the tack in more than one shot. Surface conditions may dictate higher or lower rate of application.

Water Susceptibility

Are lightweight aggregates "per se" more water susceptible than the average Texas river gravel or field sand? The answer is "No!" for materials in current production; indeed, they are less susceptible. As a matter of fact, one Texas source of lightweight aggregate is pretreated with quicklime as an inescapable part of the manufacturing procedure! The other two sources contain modest amount of quicklime.

Then do we need to treat lightweight aggregates for use in paving mixtures to minimize water damage? Usually pretreating of the asphalt or part of the aggregate is in order because dense graded lightweight aggregate paving mixtures may contain water susceptible intermediate and/or fine fractions. In cases where the fraction requiring treatment is small, the economical approach would be to treat this fraction only.

In the mix design phase, laboratory tests should be run to measure water susceptibility and construction guides should emphasize the necessary steps required to reduce the intrusion of water, namely, in place density control.

A program of preventative measure to minimize stripping is the recommended approach, mainly because once stripping advances much beyond the initial phases, reconstruction is the only technically sound approach available for solving the problem.

A number of cases of severe stripping have been observed in Texas. And, although some of the affected pavement structures contained lightweight aggregate in the surface layer, actual proof of asphalt stripping from the lightweight particles themselves has not been documented.

Another problem that may occur and one which has been observed on different jobs across the State deals with water susceptibility of the pavement layer immediately below the thin lightweight surfacing. The distress-contributing layer may be thick or thin. One example would be a thin level-up course on portland cement concrete preparatory to placing a high friction surface course. Another situation might be an asphalt stabilized hot mixed based of considerable thickness placed in new construction with this base surfaced with a thin lightweight aggregate hot mix.

If the base in the latter example is only mildly water susceptible trouble is a strong possibility when the facility is opened to traffic immediately, particularly in the fall of the year and/or in inclement weather. Where this condition exists it would be advisable, if at all practical, to delay placing the surface layer for 6 to 12 months to take advantage of traffic compaction and thorough "curing" of the susceptible base material before application of the lightweight aggregate overlay mixture.

One of the contributing problems associated with water susceptibility of the pavement layer immediately below the lightweight hot mix surfacing is the relatively high permeability of the lightweight hot mix. The high permeability is often due to selecting an improper aggregate gradation and/or improper compaction. Use of volume mixture design concepts and compaction cessation requirements presented in the report will greatly reduce or eliminate many of these water susceptibility problems.

## MAINTENANCE

Thin overlays of the type being discussed usually require maintenance of some type during their service life. In any case, preventive maintenance scores well in a cost-benefit analysis. Experience has shown, however, that distress may go undetected and progress to severe proportions before action is taken. Two modes of flexible pavement distress that may progress unnoticed to create serious problems are a) delamination and b) stripping.

Delamination is a bond failure at the interface between the substrate and the overlay. Stripping is a bond failure at the aggregate-to-asphalt interface. These will be discussed separately as they apply to maintenance operations.

Delamination may be attributed to inadequate construction guides and/or improper preparation of the surface receiving the overlay. There is no known method that is both economical and practical for correcting a debonded surface short of removing and replacing delaminated areas. Depending on the extent of the area affected the decision may be to do spot repairs or to remove and replace the entire road surface.

Raveling may be prevented or stopped when it first appears by light applications of diluted asphalt emulsion. The actual amount of residual asphalt required may be quite small, say, in the order of 0.02 to 0.06 gallons per square yard. As a general rule, a dense mixture will require less asphalt than an open overlay. Slow-setting cationic asphalt emulsions with a low pen (90±) residue are recommended for dense surfaces. A very light application of sharp sand may be required following the application of the emulsion to avoid a slick surface in the early life of the repair job.

When entire segments of lightweight hot mixes have been lost (extending completely through the surface layer) patching* or resurfacing is advised. Skin patches restricted to the wheel paths may serve to

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*If such distress is extensive and it is indicated that progressive spot failure will continue, reconstruction should be considered.

extend the life and/or the ride quality of the pavement.

Patching materials that are used for large maintenance patches in lightweight hot mixes should have skid properties similar to those of the original paving material. Lightweight hot mixes are preferred patching materials; however, hot-mixed, cold-laid lightweight mixtures have been developed and successfully placed.

## SUMMARY

The material that has been presented offers avenues of approach that may be found useful in improving the success ratio of paving jobs which utilize lightweight aggregates on pavement surface layers. The discussions cover the properties of lightweight aggregates as these affect the design, production and handling of hot mixtures. Also enclosed are suggestions for modifying plant operations to offset adverse environmental conditions.

Pavement thickness and mixture design concepts have been presented. Minimum overlay thickness have been recommended. Volumetric mixture design concepts have been presented and their use encouraged. Procedures for blending lightweight and normal weight aggregates to achieve desired polish values and skid resistance have been included in the report.

Unique construction considerations associated with the use of lightweight aggregates in hot mixes have been outlined. Plant, transportation and laydown and compaction problems associated with water presented in the lightweight aggregates have been discussed in detail. Compaction cessation requirements for lightweight asphalt concrete have been developed and are presented.

Performance problems, and maintenance problems of lightweight hot mix overlays are discussed in general. Causes for debonding or slippage and raveling are presented together with recommend preventative and corrective actions.

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Table 1. Minimum Thickness for Lightweight Asphalt Concrete Overlays.

| Type of Pavement Overlaid | Traffic Volume | Minimum thickness, inches |
|---|---|---|
| Asphalt Concrete or Chip Seal | low | 1.00 |
| | moderate | 1.25 |
| | high | 1.50 |
| Portland Cement Concrete | moderate | 1.50 |
| | high | 2.00 |

*Traffic volume categories have not been defined except by these general categories.

Table 2. Producers of Synthetic Aggregates Used in Asphalt Concrete.

| Producer | Location of Plant | Brand Name |
|---|---|---|
| Featherlite | Ranger | Featherlite |
| Texas Industries | Clodine | Hayclite |
| Texas Industries | Streetman | Superrock |

Table 3. Lightweight Aggregates Physical Property Tests

| Test Description | Texas Test Method | ASTM Test Method |
|---|---|---|
| Dry Loose Unit Weight | 404-A, Part C | C29* |
| Abrasion | 410-A | C131* |
| Freeze Thaw Loss | 432-A | |
| Pressure Slaking Value | 431-A | |
| Decantation (detrimental fines) | 217-F, Part II | |
| Gradation | 200-F, Part I | C136* |
| Absorption and Dry Bulk Specific Gravity | 433-A | |
| Polish Resistance | 438-A | E303* |

*modified version of standard ASTM test method

Table 4. Polish Value Requirement

| Polish Value Criteria For Flexible Pavements | | |
|---|---|---|
| Description of Facility or Traffic | | Polish Value Requirement |
| Present ADT | Less Than 750 | None Required |
| | 750-2000 | 30 Minimum |
| | 2000-5000 | 33 Minimum |
| | Greater Than 5000 | 35 Minimum |
| Type of Highway | Interstate | 35 Minimum or Specify Aggregate Type |
| | Special and High Volume Highway | Specify Aggregate Type |

After Reference 18.

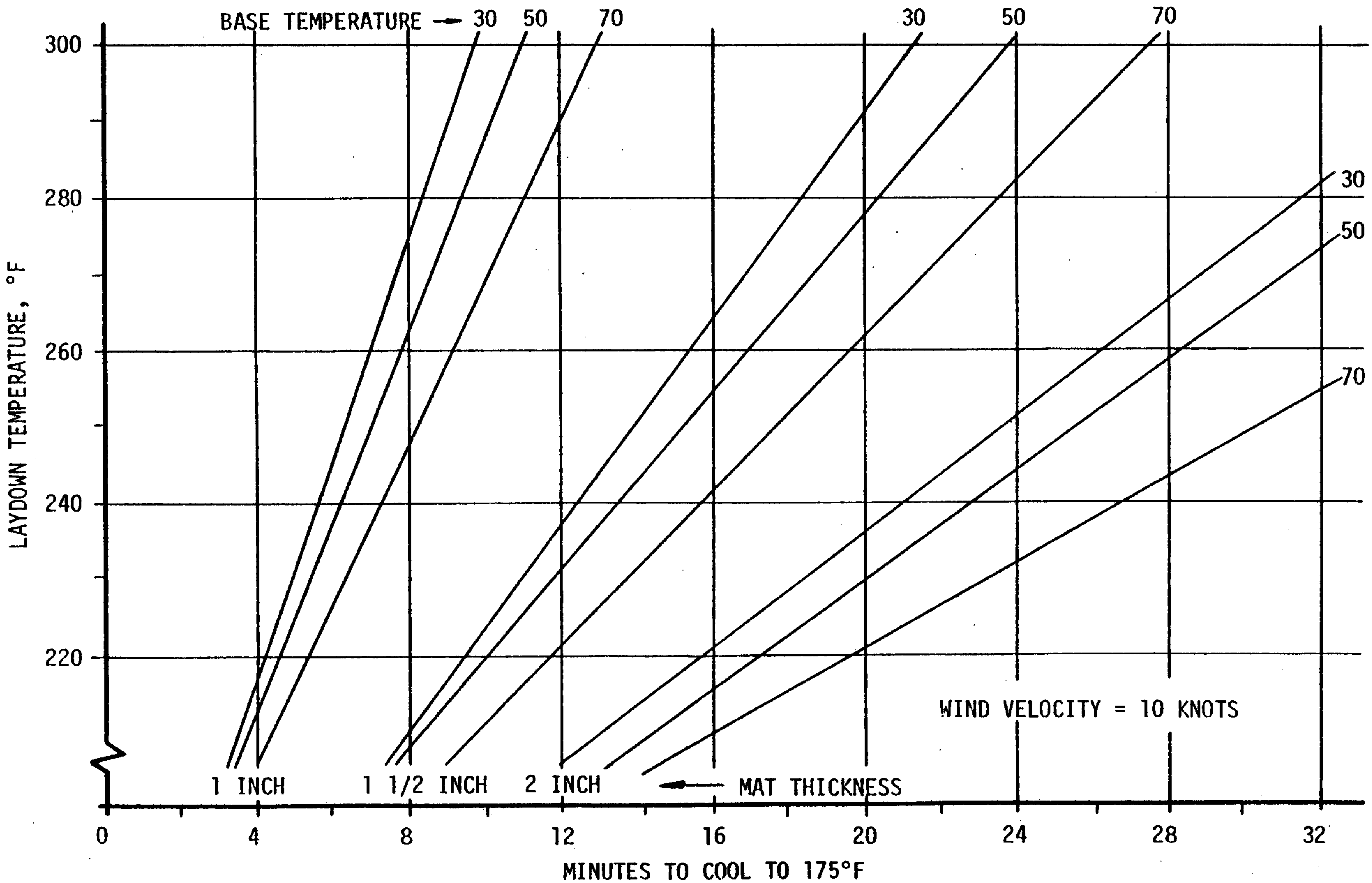



Figure 1. Effect of Base Temperature on Cooling Rate for Lightweight Aggregate Hot Mix.

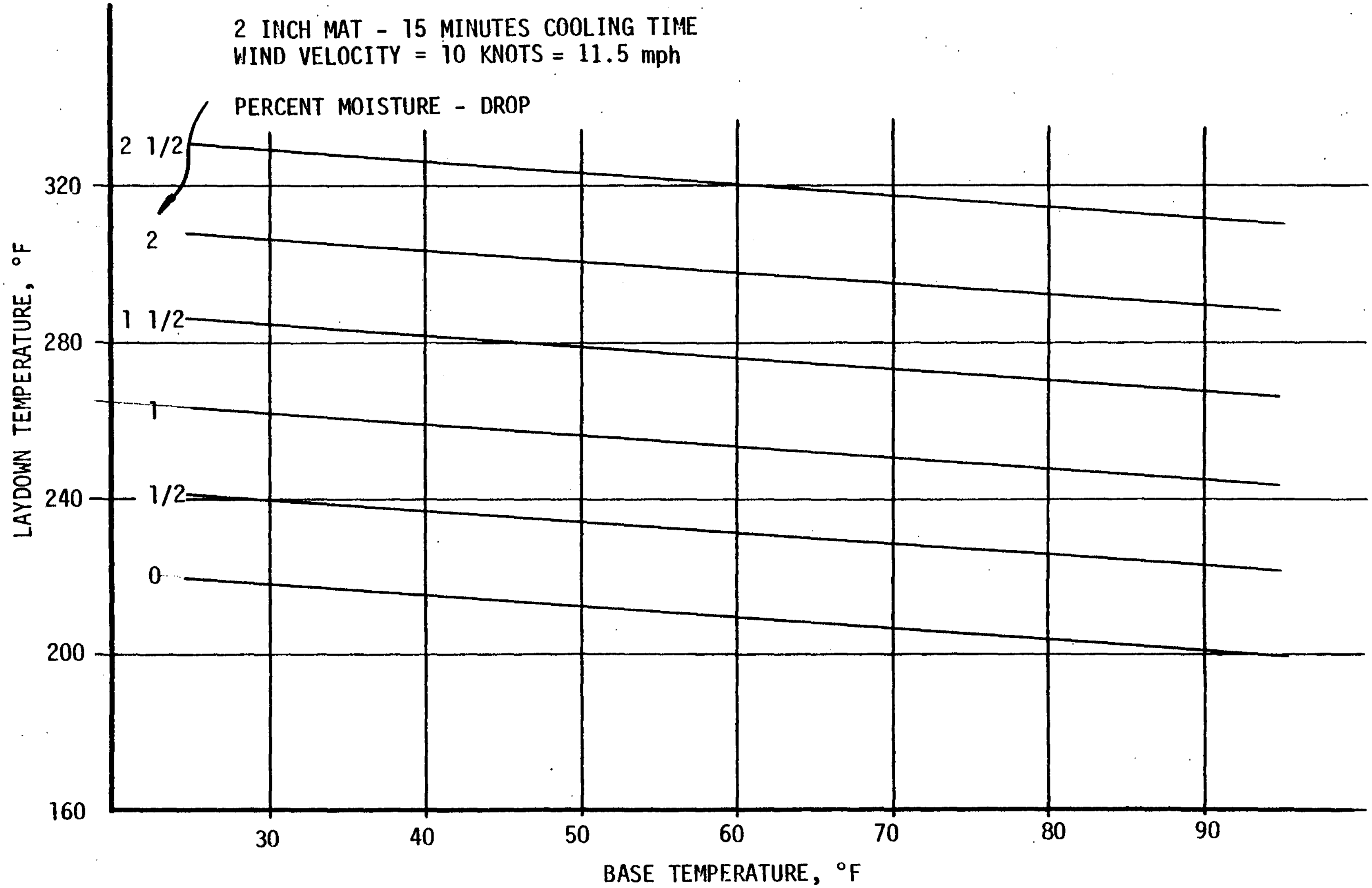



Figure 2. Cessation Requirements, 2-INCH MAT, 15-MINUTES COOLING TIME.

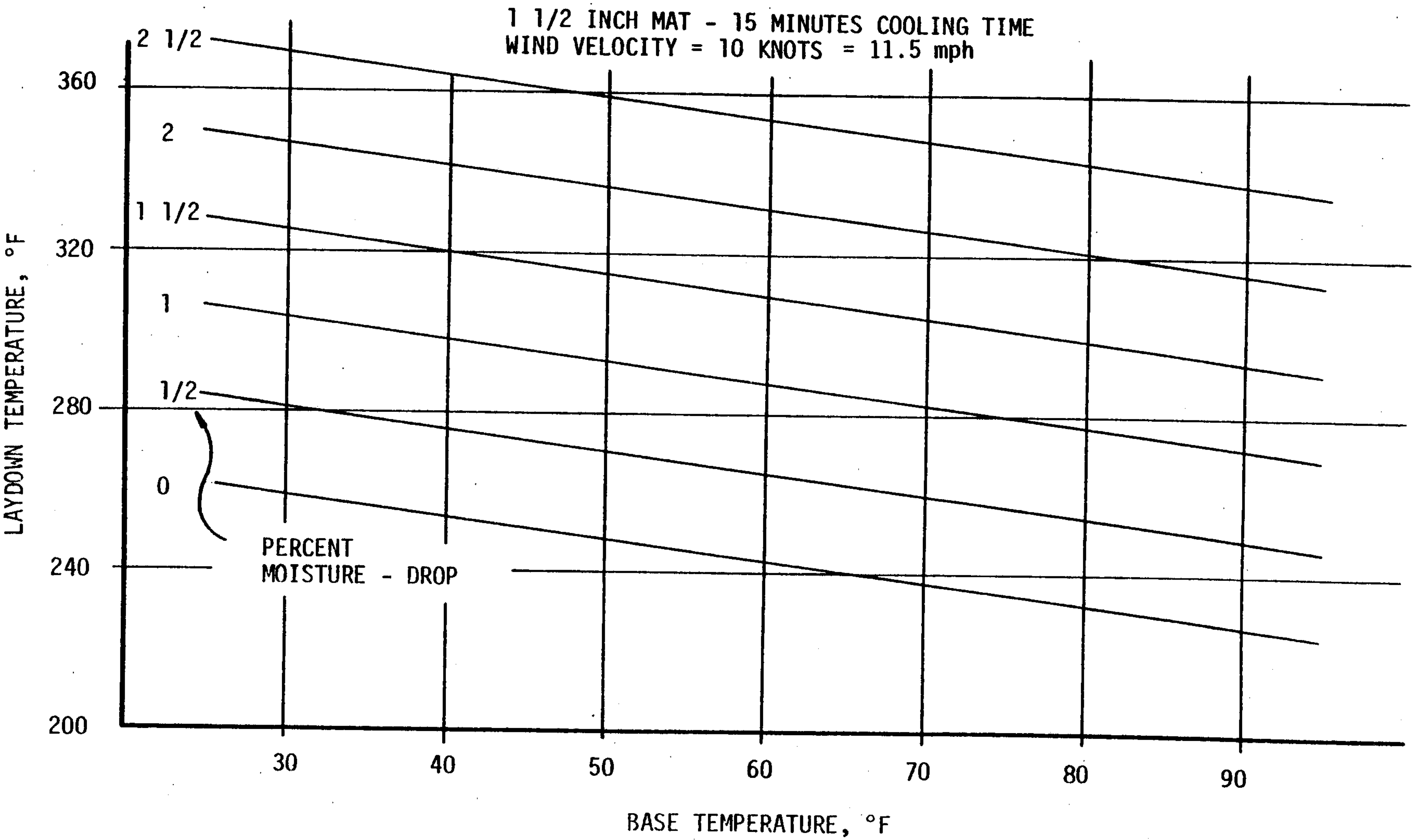



Figure 3. Cessation Requirements, 1½-INCH MAT, 15 MINUTES COOLING TIME.

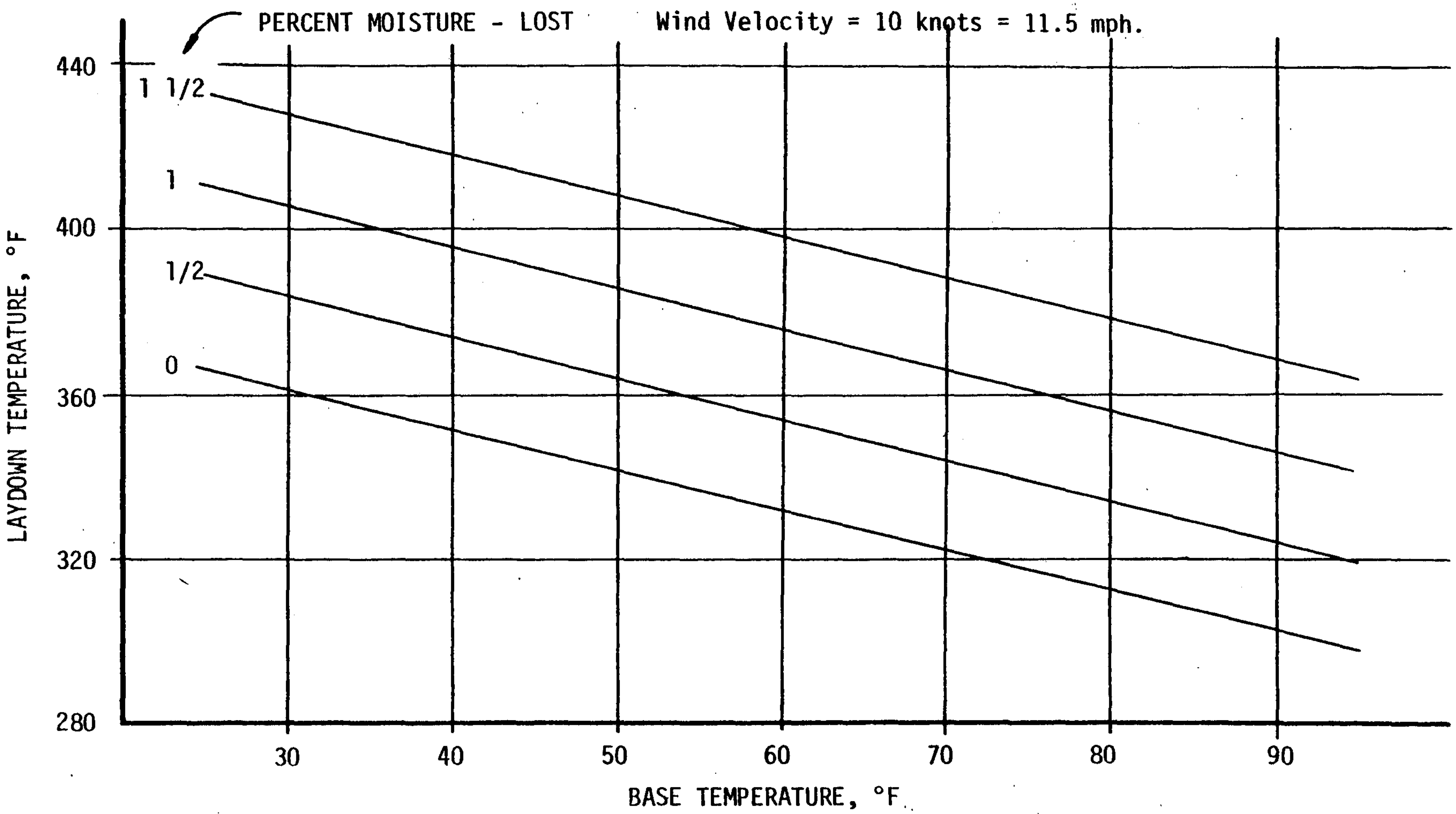



Figure 4. Cessation Requirements, 1-INCH MAT, 15 MINUTES COOLING TIME.

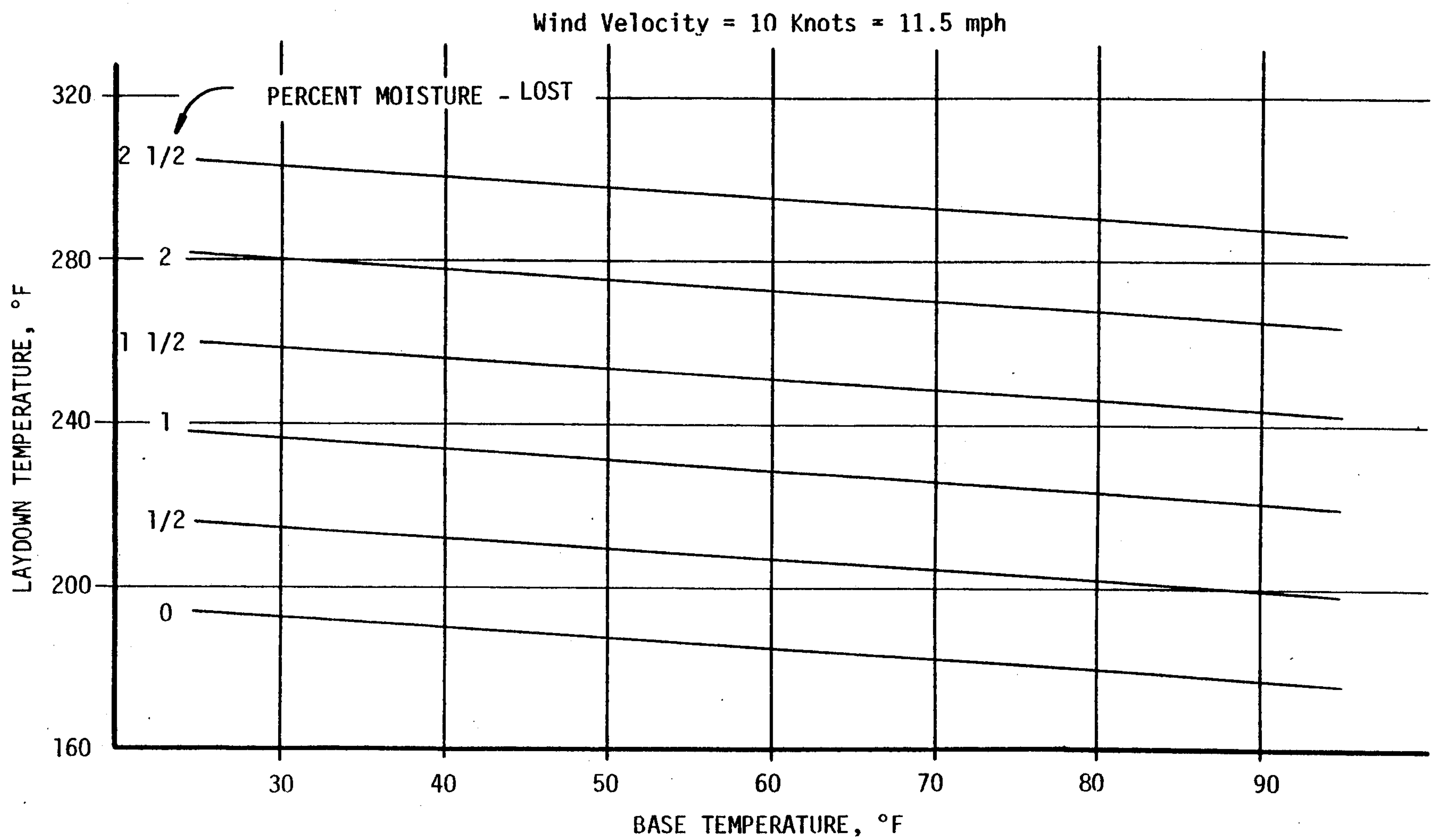



Figure 5. Cessation Requirements, 2-INCH MAT, 8 MINUTES COOLING TIME.

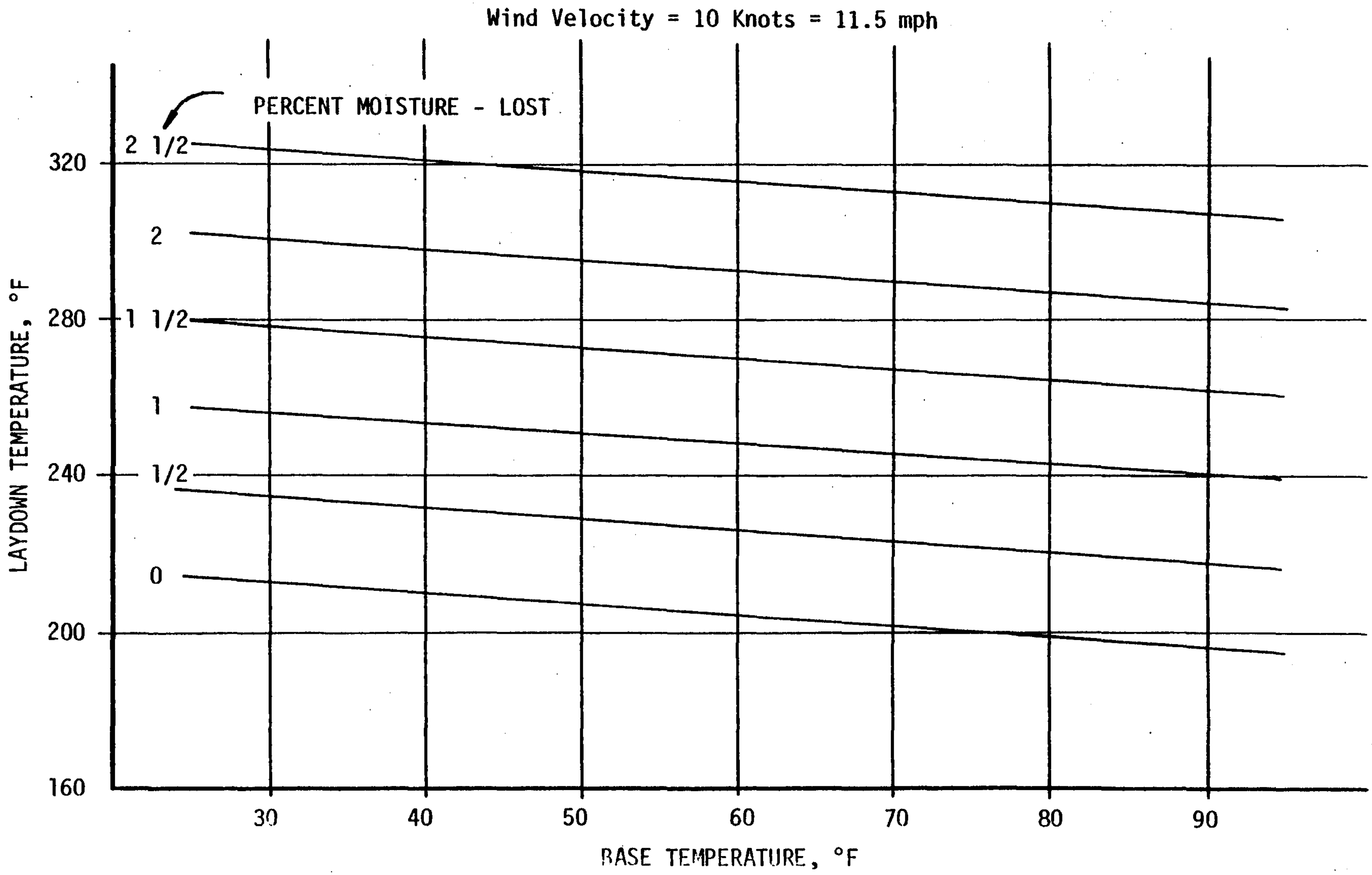



Figure 6. Cessation Requirements, 1½ INCH MAT, 8 MINUTES COOLING TIME.

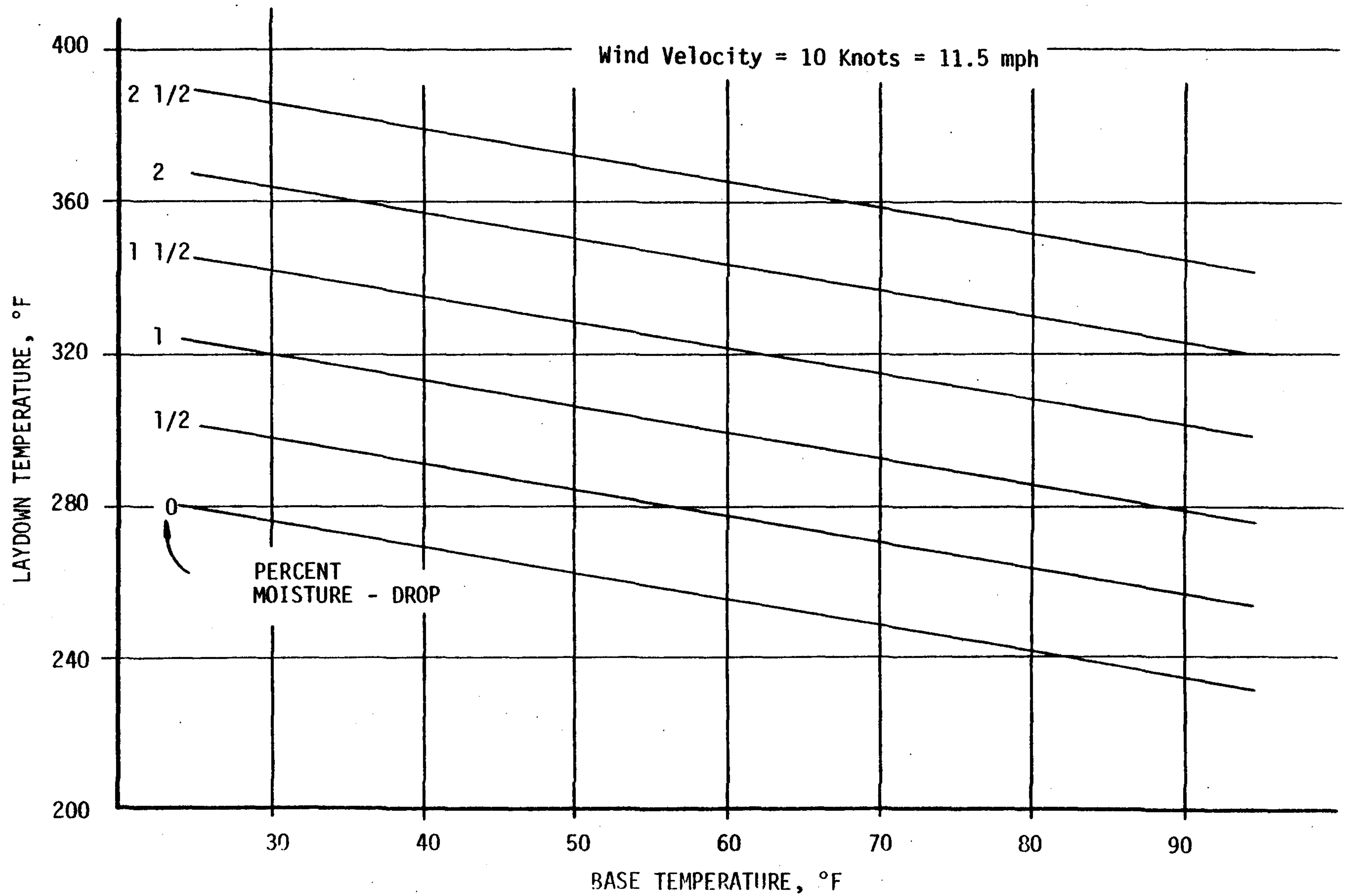



Figure 7. Cessation Requirements, 1-INCH MAT, 8-MINUTES COOLING TIME.

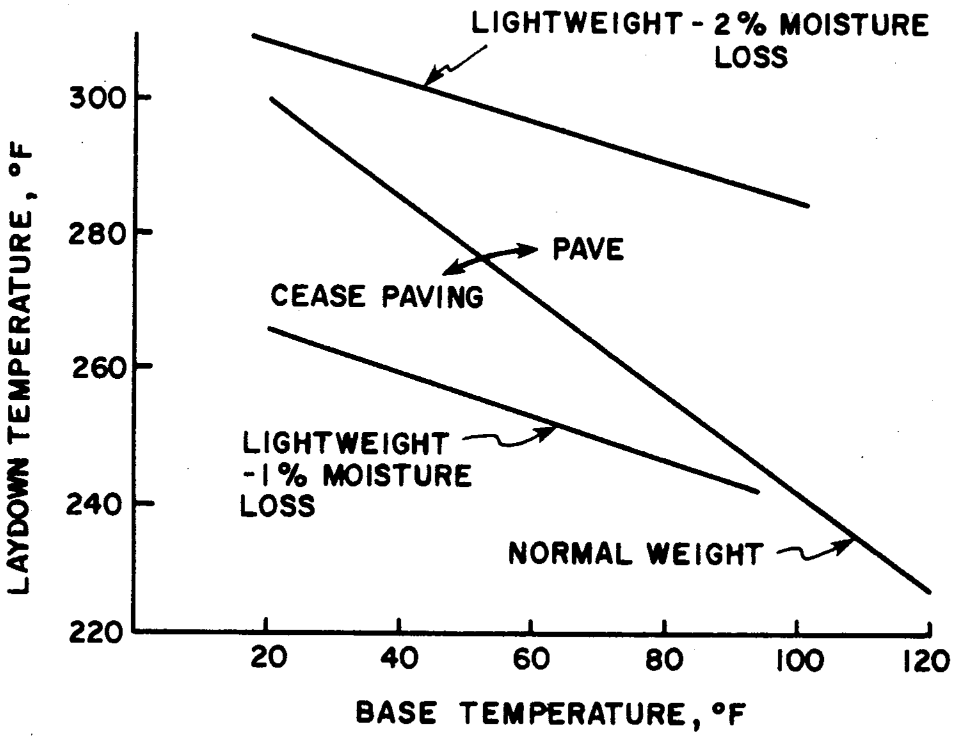



FIGURE 8. ILLUSTRATION OF SUGGESTED CESSATION REQUIREMENTS - 15 MINUTES ROLLING TIME, 2 INCH MAT, NORMAL WEIGHT AND LIGHTWEIGHT HOT MIXES

APPENDIX A

Volumetric Mixture Design Concepts

(After Reference 27)

State Department of Highways and Public Transportation

Materials and Tests Division

# DESIGN OF BITUMINOUS MIXTURES

## Scope

This procedure provides a means to determine the proper proportions of approved aggregates and asphalt which, when combined, will produce a mixture that will satisfy the specification requirements. Examples of typical procedures for design by weight or design by volume are included in this test method.

## Procedure

1. Obtain and identify representative samples consisting of approximately 50 pounds of each type of material or each size aggregate proposed for use, and dry to constant weight at a temperature of 200°F minimum.

2. Secure laboratory size samples of each aggregate by carefully reducing the amount of material by quartering as outlined in Test Method Tex-200-F. (Figure 1)

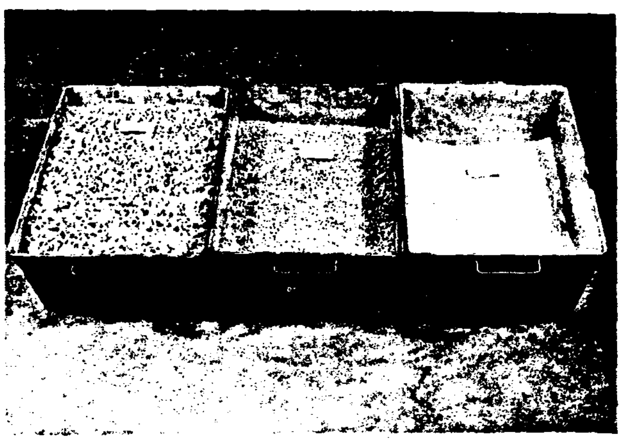


Figure 1

3. Determine the sieve analysis as outlined in Test Method Tex-200-F using the sieve sizes as set forth in the specifications for the type mix desired, and the bulk specific gravity of each size aggregate in accordance with Test Methods Tex-201-F or Tex-202-F.

4. The proper design technique requires that the aggregate proposed for use be combined in such a manner as to approach the average or mid-point of the allowable range set forth in the specifications. However, economy and ratio of production of the aggregate are factors which should be kept in mind in selecting the initial combination to be tested. Only after combinations utilizing the most economical proportions have been determined to be unsatisfactory will other less desirable combinations be tried.

5. After determining the required data in Step 3, assume, on the basis of the aggregate alone, the most satisfactory combination of the available materials which meets the requirements set forth in Step 4. Calculate the combined sieve analysis on Form D-9-F 24 (Table 2). In the event this assumed combination is at any point outside the specified grading limitations or, in the opinion of the Engineer, too close to these limits for consistent acceptable plant production, other combinations will be tried.

6. After the design gradation has been selected, the necessary asphalt content must be determined which will enable the mixture to satisfy the density (percent compaction), stability values specified and other requirements of the governing specification. Unless previous experience with these aggregates justifies the use of a smaller asphalt range, the method for selecting the proper asphalt content is to prepare five mixtures containing five different asphalt contents which cover the allowable range of the specifications. The percentages of asphalt to be tried are each end-point, the mid-point, and the two quarter-points of the allowable range shown in the specification. A trial specimen should be molded so that any necessary corrections can be made in the amount of material necessary to obtain a standard specimen height of 2.0 ± 0.06 inches. The asphalt content of the trial specimen should be at the mid-point of the specification range. After calculating the correct weight to produce the trial specimen of standard height, the total weights for specimens containing other percentages of asphalt can be closely approximated in most instances by using the corrected weight of the trial specimen as a base value and for every one percent by weight change in percentage by weight of asphalt, change the total weight by 5 grams.

7. Combine materials, mix and mold specimens 4 inches in diameter and 2.0 ± 0.06 inches in height as described in Test Method Tex-205-F and Tex-206-F.

8. When the quality tests include the sand equivalent value, perform this test on the combined materials prior to the addition of asphalt as set forth in Test Method Tex-203-F.

9. Determine the density or percent compaction of the specimen according to Test Method Tex-207-F.

10. Determine the stabilometer value or percent stability of the specimens as described in Test Method Tex-208-F.

11. Plot the test values obtained from the density and stability determinations versus the percent asphalt as illustrated in Figure 2. From this curve the percent asphalt which will provide a mixture that will satisfy the density and stability requirements of the specifications can be determined. If there is not an asphalt content within the allowable range which will provide such a mixture, it will be necessary to assume another combination of aggregates, or, possibly, even obtain new materials and perform a new design as outlined herein.

## PART I

## TYPICAL EXAMPLE OF DESIGN BY WEIGHT

Conditions

1. The processed materials consist of crushed limestone for the coarse aggregate, Aggregate "A" (1/2-inch maximum size) and medium size aggregate, Aggregate "B" (1/4-inch maximum size) and a fine siliceous sand obtained from a local pit.

2. It is desired to combine the three aggregates and penetration grade asphalt in such proportions to meet the requirements of grading, density and stability of Specification Item 340, Type D for Asphaltic Concrete.

Solution

1. Obtain representative laboratory samples of the aggregates as set forth in the Procedure of this Test Method. The results of the sieve analysis of each type material are shown in Table I.

2. After considering all factors relating to the production, etc., of the available materials, assume that the most economical combination of the aggregates will consist of 35% by weight coarse aggregate (Aggregate "A"), 22% by weight medium aggregate (Aggregate "B") and 43% by weight of field sand.

Table II on Form D-9-F-24 shows the resulting bin sieve analysis and the combined grading along with the specification grading for Item 340, Type "D".

3. The test mixtures are designed on the basis of the combined weight of the aggregate and asphalt, e.g., the total weight of the asphaltic mixtures. The combined grading of the aggregates is changed to include the asphalt as shown in Table III. The asphalt content allowed for Type D is 4.0% to 8.0% by weight and as previously stated, the suggested asphalt contents for the test mixes are the end points, the midpoint and the two quarter-points of the allowable asphalt spread. In this example these will be: 4.0, 5.0, 6.0, 7.0 and 8.0 percent by weight. Therefore, the corresponding percentages by weight of the aggregate in the mixtures will be 96.0, 95.0, 94.0, 93.0 and 92.0.

4. A total weight of 1000 grams for any mixture will usually produce a standard specimen approximately 2.00 inches in height and is an easy, convenient figure to work with in calculating the design mixes. After the mixes have been calculated on the basis of 1000 grams total weight, a trial mixture should be mixed and molded at the mid-point of the asphalt range specified to obtain the actual specimen height this total weight will produce. The total weight for this trial mixture can then be corrected by direct proportion as shown in Table III for the proper total weight for a 2.00 inch high specimen. After this correct weight has been determined for the trial mixture, the corrected weights for all the remaining design mixtures can be calculated to a close approximation by adding to or subtracting from the total weight of the trial mixture 5 grams for every one percent increase or decrease in the asphalt content. For the example in Table III, 8.0% by weight asphalt content was used to show this correction from a trial mixture containing 6.0% by weight of asphalt.

5. After correcting the weights for the design mixes, combine the materials, mix and mold the test specimens and obtain the percent density and stability values as described in Test Methods Tex-205-F, 206-F, 207-F and 208-F.

6. The following table shows the average values obtained from the above tests.

| Percent Asphalt | Average Percent Density | Average Percent Stability |
|---|---|---|
| 4.0 | 92.0 | 44 |
| 5.0 | 93.9 | 45 |
| 6.0 | 96.1 | 40 |
| 7.0 | 97.5 | 29 |
| 8.0 | 98.3 | 16 |

7. To obtain the optimum asphalt content for the design, the above test values are plotted on a sheet of graph paper with specimen density and stability on the vertical axis and percent asphalt on the horizontal axis. The density and stability curves are drawn by connecting the respective plotted values (Figure 2). Since the standard specifications specify an optimum density of 97%, a line is drawn vertically down the sheet from the point at which the density curve intersects the 97% density line. This vertical line intersects both the stability curve and the horizontal axis.

The optimum asphalt content, as read from the graph, is 6.7% by weight and the expected laboratory stability of this mixture would be 33%. The above procedure has established a bituminous mixture design based on either stockpile or cold bin aggregates. The design indicates the material should be fed to the plant in the following proportions:

| | |
|---|---|
| Fine Sand | = 43.0% |
| Medium Aggregate "B" | = 22.0% |
| Coarse Aggregate "A" | = 35.0% |

If the materials are carefully proportioned in this manner and the screens of the plant are properly chosen and operate efficiently, the resulting combined hot bin aggregate should closely approximate the design gradation. Experience has proven, however, that this ideal situation rarely exists.

In order to provide the producer with batch weights for plant production, a complete sieve analysis of each hot bin is necessary. Then a combined grading of these hot bin materials is developed in exactly the same manner as described previously for the cold bin or stockpile aggregates. (This constitutes a new design based on hot bin sieve analyses.) This new combined grading should be as nearly identical to the original grading as possible so that the resulting mixture will have characteristics similar to the laboratory designed mixture.

As an example, assume that the second design has been made based upon the hot bin sieve analysis, and that this design resulted in Bin No. 1 (Fine Aggregate) providing 40% of the aggregate, Bin No. 2 (Medium Aggregate) providing 25% of the aggregate, and Bin No. 3 (Coarse Aggregate) providing the remaining 35% of the aggregate. This combination of aggregates would result in a new combined grading that closely approximates the original design.

The batch weights needed by the producer to produce the mixture would include the weight of aggregate from each bin and the weight of asphalt. The original design established an optimum asphalt content of 6.7% by weight. Therefore, the aggregate would constitute 93.3% by weight of the mixture. The proper proportion of each material in the final mixture would result as follows:

| | | |
|---|---|---|
| Bin No. 1 (Fine) | 40% x 93.3% | = 37.3% |
| Bin No. 2 (Medium) | 25% x 93.3% | = 23.3% |
| Bin No. 3 (Coarse) | 35% x 93.3% | = 32.7% |
| | Asphalt | = 6.7% |

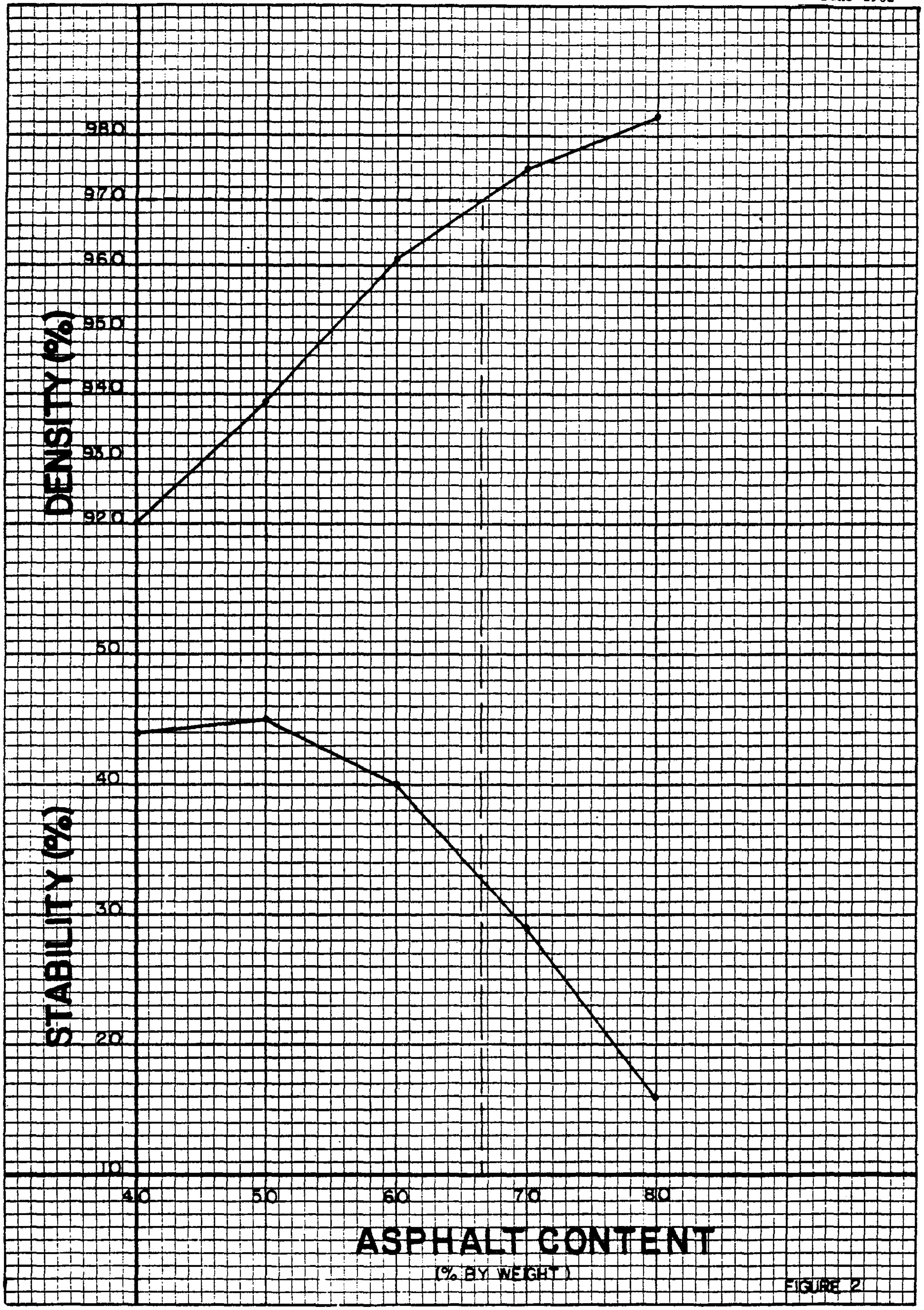
Assuming that the plant will produce a 4000 pound batch, the batch weights are as follows:

| | | |
|---|---|---|
| Bin No. 1 | = 37.3% x 4000 | = 1492 lbs. |
| Bin No. 2 | = 23.3% x 4000 | = 932 lbs. |
| Bin No. 3 | = 32.7% x 4000 | = 1308 lbs. |
| Asphalt | = 6.7% x 4000 | = 268 lbs. |
| | Total | = 4000 lbs. |

**Notes:**

**1. Keep the various sizes of aggregate, as shown in Table III, separate and recombine to make the three test specimens for each percent asphalt uniform and as near identical as possible.**

**2. In calculating design quantities, keep in mind that the sum of the combined aggregates must equal 100 percent, and that the sum of the total mixture of aggregate and asphalt will also be 100%.**


DENSITY (%)
98.0
97.0
96.0
95.0
94.0
93.0
92.0
STABILITY (%)
50
40
30
20
10
4.0
5.0
6.0
7.0
8.0
ASPHALT CONTENT
(% BY WEIGHT)
FIGURE 2

# MATERIALS AND TESTS DIVISION
## BITUMINOUS SECTION
## SIEVE ANALYSIS

| | |
|---|---|
| Date 1-2-61 | District No. M & T Laboratory |
| Time | Req. No. Hot-Mix Plant Stockpiles |
| Spec. Item No. 340 | Project No. |
| Type D | Design No. D-1 |

| SIEVE ANALYSIS, % BY WEIGHT | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sieve Size | ~~Car No.~~ Fine Sand | ~~Car No.~~ Aggregate "B" Medium Agg. | ~~Car No.~~ Aggregate "A" Coarse Agg. | Car No. | Car No. | Car No. | Car No. | Car No. | Car No. | Car No. | T.H.D. Specs. |
| Retained ~~Pass~~ 1/2" | | | 0.0 | | | | | | | | |
| Retained ~~Pass~~ 3/8" | | | 3.0 | | | | | | | | |
| 1 3/4" – 7/8" | | | | | | | | | | | |
| 7/8" – 3/8" | | | | | | | | | | | |
| 5/8" – 3/8" | | | | | | | | | | | |
| 3/8" – No.4 | | 0.2 | 89.1 | | | | | | | | |
| 1/4" – No.4 | | | | | | | | | | | |
| 1/4" – No.10 | | | | | | | | | | | |
| No.4 – No.10 | | 94.1 | 7.5 | | | | | | | | |
| Ret. No.10 | | | | | | | | | | | |
| No.10 – No.40 | 40.2 | | | | | | | | | | |
| No.40 – No.80 | 39.2 | | | | | | | | | | |
| No.80 – No.200 | 14.4 | | | | | | | | | | |
| Pass No.200 | 6.2 | 5.7 | 0.4 | | | | | | | | |
| Total | 100.0 | 100.0 | 100.0 | | | | | | | | |
| Asphalt Added | | | | | | | | | | | |

Inspector

Form No. D-9-F23

Table 2

# MATERIALS AND TESTS DIVISION
## BITUMINOUS SECTION
## MIX DESIGN SHEET

| | | | |
|---|---|---|---|
| **Date** | 1-2-61 | **District No.** | M&T Laboratory |
| **Spec. Item No.** | 340 | **Material Ident.** | Hot Mix Plant Stockpiles |
| **Type** | D | **Design No.** | D-1 |

| **Sieve Size** | Fine Sand | | Aggregate "B" Medium | | Aggregate "A" Coarse | | | | | | **Comb. Grad.** | **T.H.D. Specs.** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Sieve Analysis** | 43% | **Sieve Analysis** | 22% | **Sieve Analysis** | 35% | **Sieve Analysis** | | **Sieve Analysis** | | | |
| Retained ~~Pass~~ 1/2" | | | | | 0.0 | | | | | | 0.0 | 0.0 |
| Retained ~~Pass~~ 3/8" | | | | | 3.0 | 1.1 | | | | | 1.1 | 0-5 |
| 1 3/4" – 7/8" | | | | | | | | | | | | |
| 7/8" – 3/8" | | | | | | | | | | | | |
| 5/8" – 3/8" | | | | | | | | | | | | |
| 3/8" – No.4 | | | 0.2 | 0.0 | 89.1 | 31.2 | | | | | 31.2 | 20-50 |
| 1/4" – No.4 | | | | | | | | | | | | |
| 1/4" – No.10 | | | | | | | | | | | | |
| No.4 – No.10 | | | 94.1 | 20.7 | 7.5 | 2.6 | | | | | 23.3 | 10-30 |
| Ret. No.10 | | | | | | | | | | | 55.6 | 50-70 |
| No.10 – No.40 | 40.2 | 17.3 | | | | | | | | | 17.3 | 0-30 |
| No.40 – No.80 | 39.2 | 16.8 | | | | | | | | | 16.8 | 4-25 |
| No.80 – No.200 | 14.4 | 6.2 | | | | | | | | | 6.2 | 3-25 |
| Pass No.200 | 6.2 | 2.7 | 5.7 | 1.3 | 0.4 | 0.1 | | | | | 4.1 | 0-8 |
| Total | 100.0 | 43.0 | 100.0 | 22.0 | 100.0 | 35.0 | | | | | 100.0 | |

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**Inspector**

**Form No. D-9-F24**

## TABLE III

## DESIGN OF LABORATORY MIXES

| Material | Size | Agg. % | Mix No. 1, 6.0% Asphalt 94.0% Aggregate | | | | Mix No. 2, 8.0% Asphalt 92.0% Aggregate | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mix (%) | Wt. (Gms.) | Cumul. Wt. (Gms.) | Corrected Cumul. Wt. (Gms.) | Mix (%) | Wt. (Gms.) | Cumul. Wt. (Gms.) | Corrected Cumul. Wt. (Gms.) |
| Bin No. 3 (Coarse) | 3/8 - No. 4 | 35.0 | 32.9 | 329.0 | 329.0 | 316.3 | 32.2 | 322.0 | 322.0 | 312.8 |
| Bin No. 2 (Medium) | No. 4 - No. 10 | 22.0 | 20.7 | 207.0 | 536.0 | 515.4 | 20.2 | 202.0 | 524.0 | 509.1 |
| Bin No. 1 (Fine) | Minus No. 10 | 43.0 | 40.4 | 404.0 | 940.0 | 903.8 | 39.6 | 396.0 | 920.0 | 893.8 |
| Asphalt | | | 6.0 | 60.0 | 1000.0 | 961.5 | 8.0 | 80.0 | 1000.0 | 971.5 |
| | | 100.0 | 100.0 | 1000.0 | | | 100.0 | 1000.0 | | |

TRIAL SPECIMEN HEIGHT = 2.08 INCHES

Correct Weight for 2.00 inch specimen = $\frac{2.00}{2.08}$ (1000) = 961.5 gms.

Corrected total weight for 2.00 inch specimen with 8.0% asphalt = 961.5 + (8.0 - 6.0) (5) = 971.5 gms.

Corrected cumulative weights for 8.0% asphalt = (Cumul. Wt.) $\left(\frac{971.5}{1000}\right)$

## PART II

### TYPICAL EXAMPLE OF DESIGN BY VOLUME

The Volumetric Design Method may be beneficial to use when designing bituminous mixtures using aggregates of widely differing specific gravities.

1. The processed materials consist of the following:

   Coarse Aggregate-Aggregate, 1/2 inch maximum size.

   Medium Aggregate-Aggregate, 3/8 inch maximum size.

   Fine Aggregate-Aggregate, the majority of which passes the No. 10 sieve.

2. It is desired to combine the three aggregates and asphalt cement in such proportions to meet the requirements of grading, density, and stability of the specifications.

3. Obtain representative laboratory samples of the aggregates as set forth in the "Procedure" of this Test Method.

4. After drying to constant weight, perform sieve analysis on each individual material according to Test Method Tex-200-F. Test results are recorded on the accompanying Mix Design Sheet, No. 1.

5. Separate each individual aggregate into sizes corresponding to specification and type grade fractions. Determine the Bulk Specific Gravity, Test Method Tex-201-F, on each size fraction of the materials retained on the 80 mesh sieve and the Apparent Specific Gravity, Test Method Tex-202-F, on material passing the 80 mesh sieve.

6. Determine the Average Bulk Specific Gravity of each individual aggregate, fine, medium, and coarse, according to Test Method Tex-201-F.

Note: Assume the specific Gravity of each size fraction of each individual aggregate is equal to the Average Bulk Specific Gravity of each individual aggregate, then the percentages obtained in the sieve analysis, Test Method Tex-200-F, can be considered percentages by volume or percentages by weight.

7. Beginning with the coarse aggregate, assume percentages of each individual aggregate (totaling 100 percent) which by trial and error will produce a combined grading which satisfies the specifications item gradation. Referring to the Mix Design Sheet, No. 1, the individual aggregate percentages by volume are 43% fine, 22% medium, and 35% coarse.

8. Referring to the bottom of the Mix Design Sheet No. 1, multiply the percentages of each individual aggregate by its Average Bulk Specific Gravity to obtain the calculated weights of each aggregate. Total the individual weights. Then divide the individual aggregate weights by the total weight x 100 to obtain the percentages by weight of each individual aggregate.

9. Record the sieve analyses and percentages by weight of the individual aggregates on Mix Design Sheet, No. 2. Keeping in mind that the original sieve analyses are both percentage volumes and percentage weight, use the calculated percentage by weight and the sieve analyses to obtain a combined by weight gradation.

10. Determine the average Bulk Specific Gravity for the combined by weight gradation using the percentages by weight and the Average Bulk Specific Gravity of the individual aggregates according to Test Method Tex-201-F. In the accompanying example, the Average Bulk Specific Gravity for the combined by weight gradation is:

$$GB = \frac{100}{\frac{50.9}{2.632} + \frac{25.2}{2.546} + \frac{23.9}{1.520}} = 2.224$$

11. The asphalt content range specified for this mixture is 10.0% to 19.0% by volume; the suggested asphalt contents for the laboratory mixes are the end points, the mid-point, and the two quarter points. Table I depicts a method of converting the suggested asphalt and aggregate combinations from percentages by volume to percentages by weight for laboratory batching.

12. Use the mid-point asphalt content to produce a trial specimen. A total sample weight of 1000 grams is a convenient starting weight. In the example, Table II, the mid-point asphalt content of 7.2 percent by weight is used. Multiply the percentage aggregate in the total sample (92.8%) by the percent fractions of the individual aggregates in the first column of Table II to obtain the percentage of each aggregate fraction in the mixture containing asphalt. These percentages are used to determine the cumulative batch weights as shown in the Cum. Wt. column. The mixture thus contains 72 grams asphalt and 928 grams aggregate.

The trial sample is then mixed and molded according to Test Methods Tex-205-F and Tex-206-F, respectively. The batch weight of the 1000-gram trial sample is corrected by proportion, as shown in Table II to obtain a 2.00-inch high specimen. After this corrected weight has been determined for the trial mixture, the individual cumulative weights of each aggregate size are determined by direct proportion

(Example: $\frac{\text{Corr. Wt.}}{6} = \frac{952.4}{1000}$; Corr. Wt. = 5.7 gms.)

and recorded in the Corr. Wt. column.

The corrected weights for the remaining design mixtures can be approximated by adding or subtracting from the total weight of the trial mixture 5 grams for every one percent by weight increase or decrease in asphalt content.

(Example: 9.6 - 7.2 = 2.4; 2.4 x 5.0 = 12.0; 952.4 + 12.0 = 964.4 gms. for 9.6% by weight asphalt content mixture.)

Determine the individual aggregate and asphalt weights for each of the five asphalt content mixtures. Mix and mold three Hveem specimens for each of the five mixtures. Determine the average density of each set of specimens as described in Test Method Tex-207-F. Determine the average Hveem stability for each set of specimens according to Test Method Tex-208-F.

Using the average density and stability data for each asphalt content mixture, construct the "design curves" as illustrated in Figure 2. Draw a line representing the "optimum density" (97.0% for this mixture) horizontally until it intersects the design density curve. Then draw a vertical line from this intersection to the horizontal axis. The intersection of this vertical line with the horizontal axis provides the "optimum asphalt content" for the design. (In the example, Figure 2, a mixture of the chosen aggregate gradation with 6.7% asphalt should yield a specimen density of approximately 97.0% with a Hveem stability value of approximately 33%.)

Should the resulting Hveem stability value be near or below the minimum required, a slightly lower asphalt content may be chosen or a new design may be required with different aggregates or combination of aggregates that will produce the specified characteristics.

13. This procedure has produced a bituminous mixture design based on either stockpiled or cold bin aggregates. The design indicates that the aggregates should be fed to the plant in the following proportions:

| | |
|---|---|
| Coarse | = 23.9% by weight |
| Medium | = 25.2% by weight |
| Fine | = 50.9% by weight |

If the materials are carefully proportioned in this manner and the screens of the plant are properly chosen and operate efficiently, the resulting combined hot bin aggregate should closely approximate the design gradation. Experience has proved, however, that this ideal situation rarely exists.

14. After the plant has been running for a sufficient period of time to be producing a consistent mixture gradation, samples must be taken from the hot bins to the laboratory. The specific gravities of these hot bin aggregates must be determined and a complete redesign by volume must be made in the same manner as that previously described for the cold bin or stockpiled aggregates.

Following the steps of this procedure, the percentage by weight of aggregate from each hot bin and the optimum asphalt content for the hot bin design can be determined that will satisfy the specifications.

15. As an example, assume that the special design has been made based upon the hot bin aggregate samples, and that this design resulted in Bin No. 1 (Fine Aggregate) providing 40.0% by weight of the aggregate, Bin No. 2 (Medium Aggregate) providing 25.0% by weight of the aggregate, and Bin No. 3 (Coarse Aggregate) providing the remaining 35.0% by weight of the aggregate. This combination of aggregates should result in a combined grading that approximates the original design.

Assuming that the optimum asphalt content of the second design results in the same as the original design, 6.7% by weight, the aggregate would constitute 93.3% by weight of the mixture. The proper proportion of each material in the final mixture would be as follows:

| | |
|---|---|
| Bin No. 1 | 40.0% x 93.3% = 37.3% by weight |
| Bin No. 2 | 25.0% x 93.3% = 23.3% by weight |
| Bin No. 3 | 35.0% x 93.3% = 32.7% by weight |
| Total | = 93.3% by weight |
| Asphalt | = 6.7% by weight |
| Total | = 100.0% by weight |

16. Assuming that the plant will produce a 4000-pound batch, the batch weights are as follows:

| | |
|---|---|
| Bin No. 1 | = 37.3% x 4,000 = 1,492 lbs. |
| Bin No. 2 | = 23.3% x 4,000 = 932 lbs. |
| Bin No. 3 | = 32.7% x 4,000 = 1,308 lbs. |
| Asphalt | = 6.7% x 4,000 = 268 lbs. |
| Total | = 4,000 lbs. |

Notes: For the volumetric design method, it must be realized that plant control is based upon the percent by weight combined grading resulting from the hot bin design. The periodic hot bin sieve analyses and extraction sieve analyses and residual bitumen contents must meet this combined grading and the specified tolerances.

If the grading of the mixture exceeds the tolerances in any part and it requires cold feed adjustments to correct the gradation (or should it be desirable to substitute another aggregate for one or more being used), a complete redesign by volume must be made.

The volumetric sieve analysis may be used for gradation control. In this instance both the tolerances and the standard gradation specifications will apply.

# MATERIALS AND TESTS DIVISION
## BITUMINOUS SECTION
## MIX DESIGN SHEET

NO. 1

| Date | District No. |
|---|---|
| Spec. Item No. | Material Ident. |
| Type | Design No. |

| Sieve Size | Fine | | Medium | | Coarse | | | | | | Comb. Grad. (% by Vol) | T.H.D. Specs. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sieve Analysis | 43.0% | Sieve Analysis | 22.0% | Sieve Analysis | 35.0% | Sieve Analysis | | Sieve Analysis | | | |
| + 1/2" | | | | | 0 | 0 | | | | | 0 | 0 |
| + 3/8" | | | 0 | 0 | 3.0 | 1.1 | | | | | 1.1 | 0-5 |
| 1 3/4" – 7/8" | | | | | | | | | | | | |
| 7/8" – 3/8" | | | | | | | | | | | | |
| 5/8" – 3/8" | | | | | | | | | | | | |
| 3/8" – No. 4 | | | 2.2 | 0.5 | 89.1 | 31.2 | | | | | 31.7 | 20-50 |
| 1/4" – No. 4 | | | | | | | | | | | | |
| 1/4" – No. 10 | | | | | | | | | | | | |
| No. 4 – No. 10 | 0 | 0 | 94.1 | 20.7 | 7.5 | 2.6 | | | | | 23.3 | 10-30 |
| Ret. No. 10 | | | | | | | | | | | 56.1 | 50-70 |
| No. 10 – No. 40 | 40.2 | 17.3 | | | | | | | | | 17.3 | 0-30 |
| No. 40 – No. 80 | 39.2 | 16.8 | | | | | | | | | 16.8 | 4-25 |
| No. 80 – No. 200 | 14.4 | 6.2 | | | | | | | | | 6.2 | 3-25 |
| Pass No. 200 | 6.2 | 2.7 | 3.7 | 0.8 | 0.4 | 0.1 | | | | | 3.6 | 0-8 |
| Total | 100.0 | 43.0 | 100.0 | 22.0 | 100.0 | 35.0 | | | | | 100.0 | |

| | Vol. | | Avg. Bulk Sp. Gravity | | Wt. | % By Wt. |
|---|---|---|---|---|---|---|
| Coarse— | 35.0 | x | 1.520 | = | 53.200 | 23.9 |
| Medium— | 22.0 | x | 2.546 | = | 56.012 | 25.2 |
| Fine— | 43.0 | x | 2.632 | = | 113.176 | 50.9 |
| | 100.0 | | | | 222.388 | 100.0 |

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Inspector

Form No. D-9-F24

# MATERIALS AND TESTS DIVISION
## BITUMINOUS SECTION
## MIX DESIGN SHEET

NO. 2

| | |
|---|---|
| Date | District No. |
| Spec. Item No. | Material Ident. |
| Type | Design No. |

| Sieve Size | Fine | | Medium | | Coarse | | | | | | Comb. Grad. (% by Wt.) | T.H.D. Specs. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sieve Analysis | 50.9% | Sieve Analysis | 25.2% | Sieve Analysis | 23.9% | Sieve Analysis | | Sieve Analysis | | | |
| + 1/2" | | | | | 0 | 0 | | | | | 0 | |
| + 3/8" | | | 0 | 0 | 3.0 | 0.7 | | | | | 0.7 | ± 4 |
| 1 3/4" – 7/8" | | | | | | | | | | | | |
| 7/8" – 3/8" | | | | | | | | | | | | |
| 5/8" – 3/8" | | | | | | | | | | | | |
| 3/8" – No. 4 | | | 2.2 | 0.6 | 89.1 | 21.3 | | | | | 21.9 | ± 4 |
| 1/4" – No. 4 | | | | | | | | | | | | |
| 1/4" – No. 10 | | | | | | | | | | | | |
| No. 4 – No. 10 | 0 | 0 | 94.1 | 23.7 | 7.5 | 1.8 | | | | | 25.5 | ± 4 |
| Ret. No. 10 | | | | | | | | | | | 48.1 | ± 4 |
| No. 10 – No. 40 | 40.2 | 20.5 | | | | | | | | | 20.5 | ± 3 |
| No. 40 – No. 80 | 39.2 | 19.9 | | | | | | | | | 19.9 | ± 3 |
| No. 80 – No. 200 | 14.4 | 7.3 | | | | | | | | | 7.3 | ± 3 |
| Pass No. 200 | 6.2 | 3.2 | 3.7 | 0.9 | 0.4 | 0.1 | | | | | 4.2 | ± 2 |
| Total | 100.0 | 50.9 | 100.0 | 25.2 | 100.0 | 23.9 | | | | | 100.0 | |

Inspector

Form No. D-9-F24

TABLE I

| | % By Vol. | | Avg. Bulk Sp. Gravity | | Wt. | % By Wt. |
|---|---|---|---|---|---|---|
| Combined Aggregate | 90.0 | x | 2.224 | = | 200.16 | 95.2 |
| Asphalt Content | 10.0 | x | 1.012 | = | 10.12 | 4.8 |
| | 100.0 | | | | 210.28 | 100.0 |
| Combined Aggregate | 87.7 | x | 2.224 | = | 195.04 | 94.0 |
| Asphalt Content | 12.3 | x | 1.012 | = | 12.45 | 6.0 |
| | 100.0 | | | | 207.49 | 100.0 |
| Combined Aggregate | 85.5 | x | 2.224 | = | 190.15 | 92.8 |
| Asphalt Content | 14.5 | x | 1.012 | = | 14.67 | 7.2 |
| | 100.0 | | | | 204.82 | 100.0 |
| Combined Aggregate | 83.2 | x | 2.224 | = | 185.04 | 91.6 |
| Asphalt Content | 16.8 | x | 1.012 | = | 17.00 | 8.4 |
| | 100.0 | | | | 202.04 | 100.0 |
| Combined Aggregate | 81.0 | x | 2.224 | = | 180.14 | 90.4 |
| Asphalt Content | 19.0 | x | 1.012 | = | 19.23 | 9.6 |
| | 100.0 | | | | 199.37 | 100.0 |

TABLE II

| Identification | % By Wt. | 7.2% Asphalt % By Wt. | 7.2% Asphalt Cum. Wt. (gms.) | 7.2% Asphalt Corr. Wt. (gms.) | 9.6% Asphalt % By Wt. | 9.6% Asphalt Cum. Wt. (gms.) | 9.6% Asphalt Corr. Wt. (gms.) |
|---|---|---|---|---|---|---|---|
| Coarse | | | | | | | |
| Ret. 3/8" | 0.7 | 0.6 | 6 | 5.7 | 0.6 | 6 | 5.8 |
| 3/8"-No.4 | 21.3 | 19.8 | 204 | 194.3 | 19.3 | 199 | 191.9 |
| No.4-No.10 | 1.8 | 1.7 | 221 | 210.5 | 1.6 | 215 | 207.3 |
| Pass No.10 | 0.1 | 0.1 | 222 | 211.4 | 0.1 | 216 | 208.3 |
| Medium | | | | | | | |
| 3/8"-No.4 | 0.6 | 0.6 | 228 | 217.1 | 0.6 | 222 | 214.1 |
| No.4-No.10 | 23.7 | 22.0 | 448 | 426.7 | 21.4 | 436 | 420.5 |
| Pass No.10 | 0.9 | 0.8 | 456 | 434.3 | 0.8 | 444 | 428.2 |
| Fine | 50.9 | 47.2 | 928 | 883.8 | 46.0 | 904 | 871.8 |
| Asphalt | ---- | 7.2 | 1000 | 952.4 | 9.6 | 1000 | 964.4 |
| | 100.0 | 100.0 | | | 100.0 | | |

Weight Correction for Specimen Height

$$\frac{\text{Corr. Wt.}}{2.00''} = \frac{1000 \text{ gms.}}{2.10''}$$

$$\text{Corr. Wt.} = \frac{2000}{2.10} = 952.4 \text{ gms.}$$

# APPENDIX B

## Cooling Curves for Lightweight Aggregate Hot Mixtures

(After Reference 21)

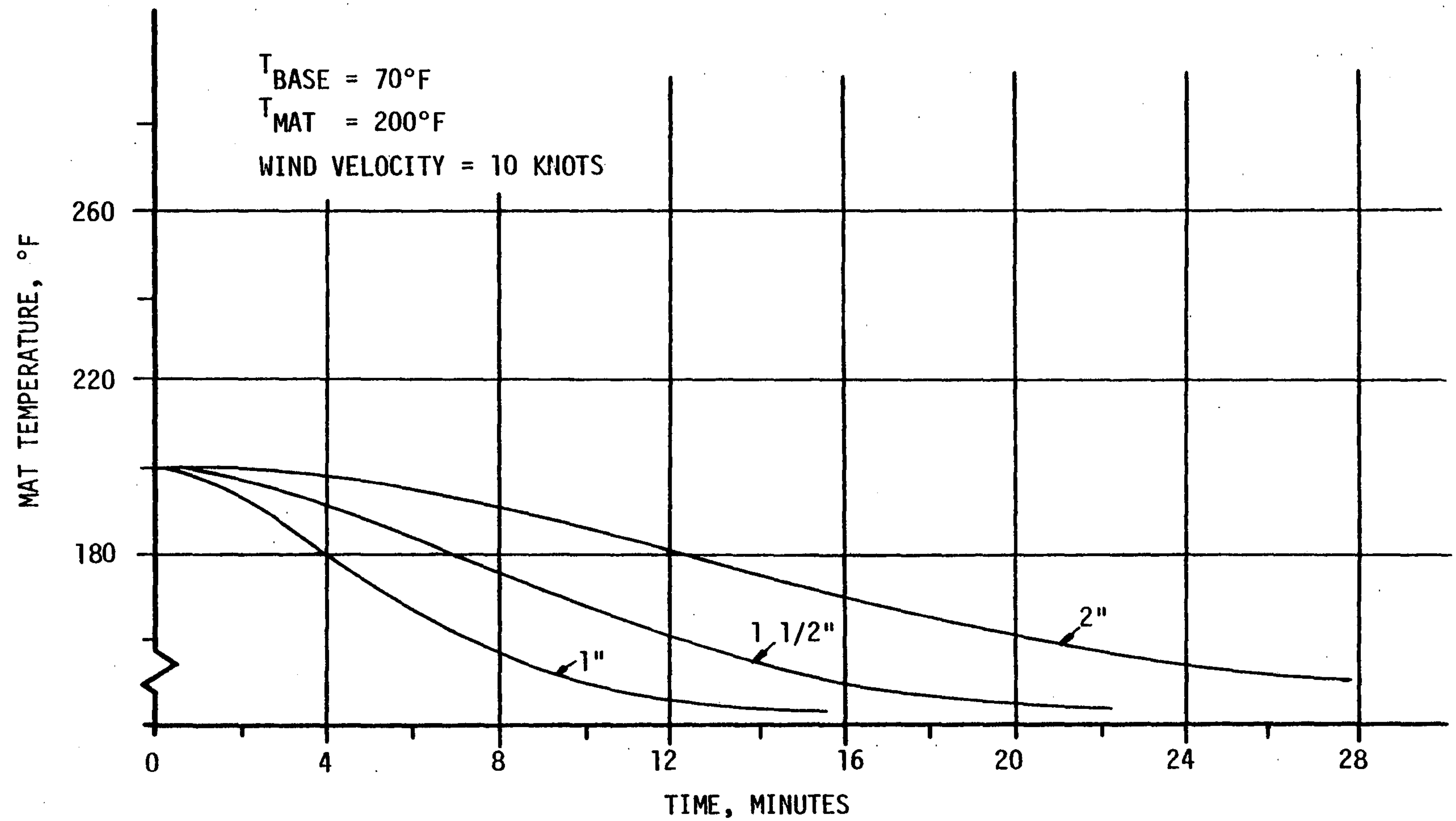


Figure B-1. Cooling Curves for Lightweight Aggregate Hot Mix ($T_{mat}$ = 200°F).

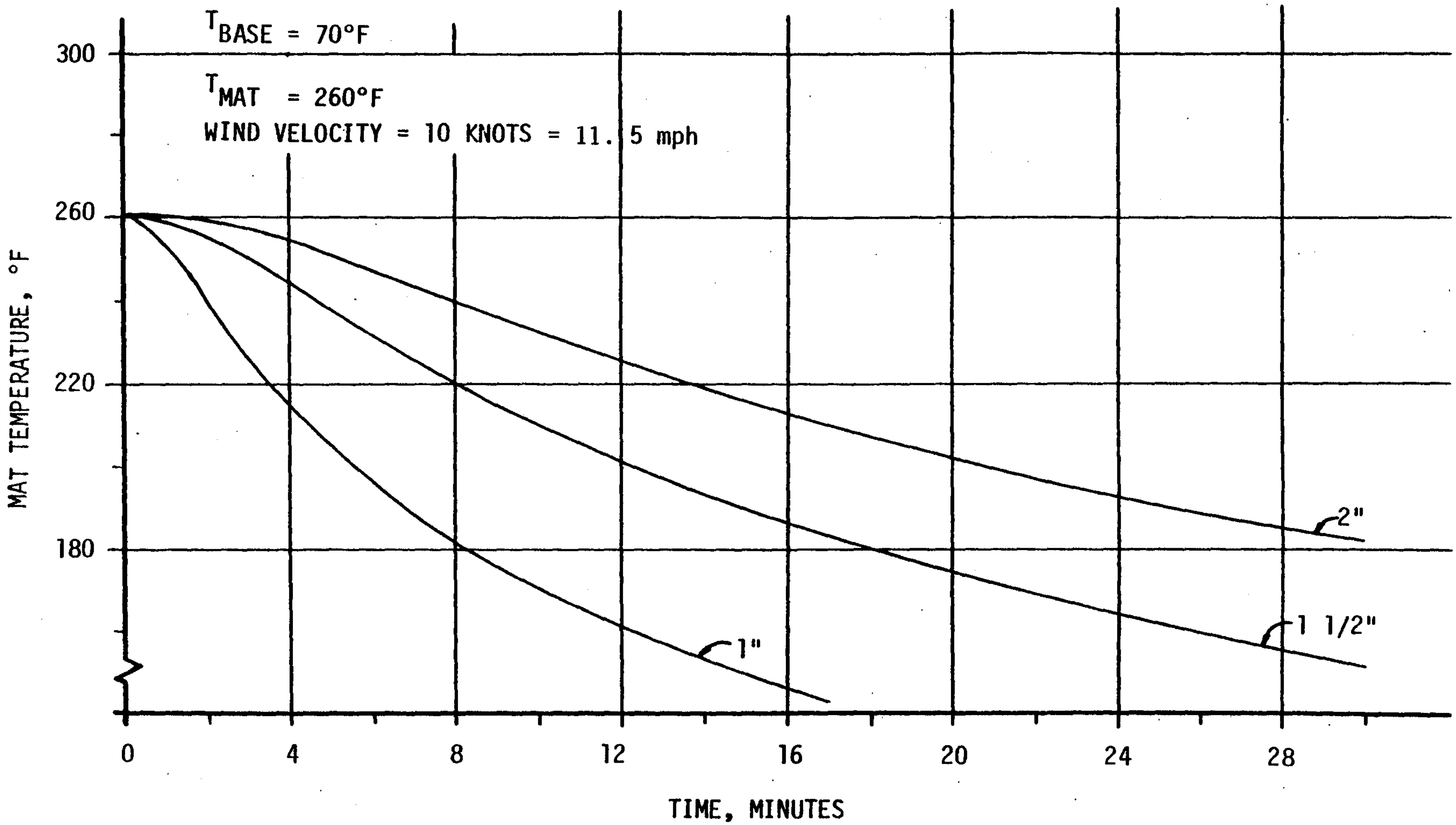


Figure B-3 Cooling Curves for Lightweight Aggregate Hot Mix ($T_{mat}$ = 260°F.)

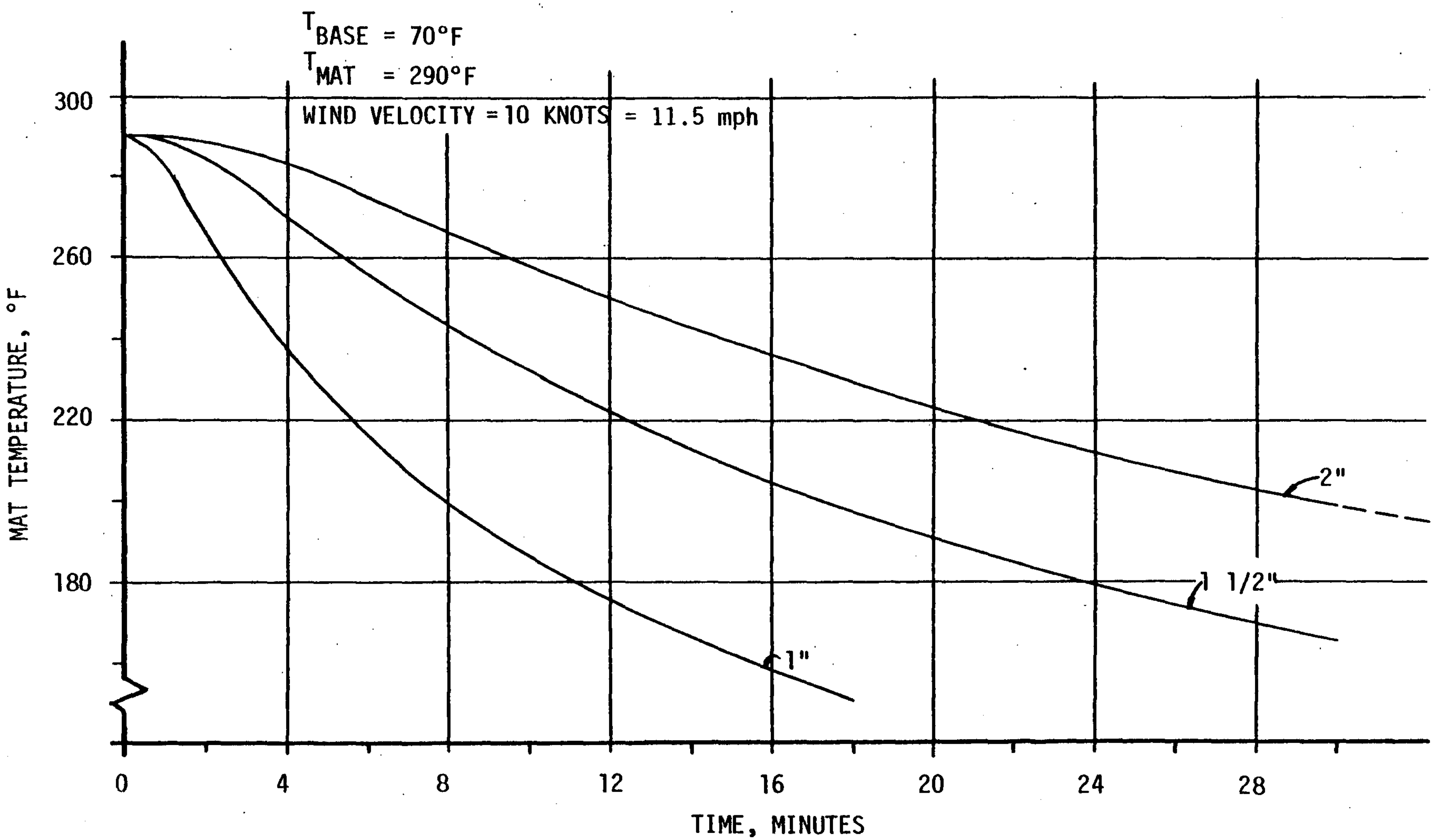


Figure B-4 Cooling Curves for Lightweight Aggregate Hot Mix ($T_{mat}$ = 290°F).

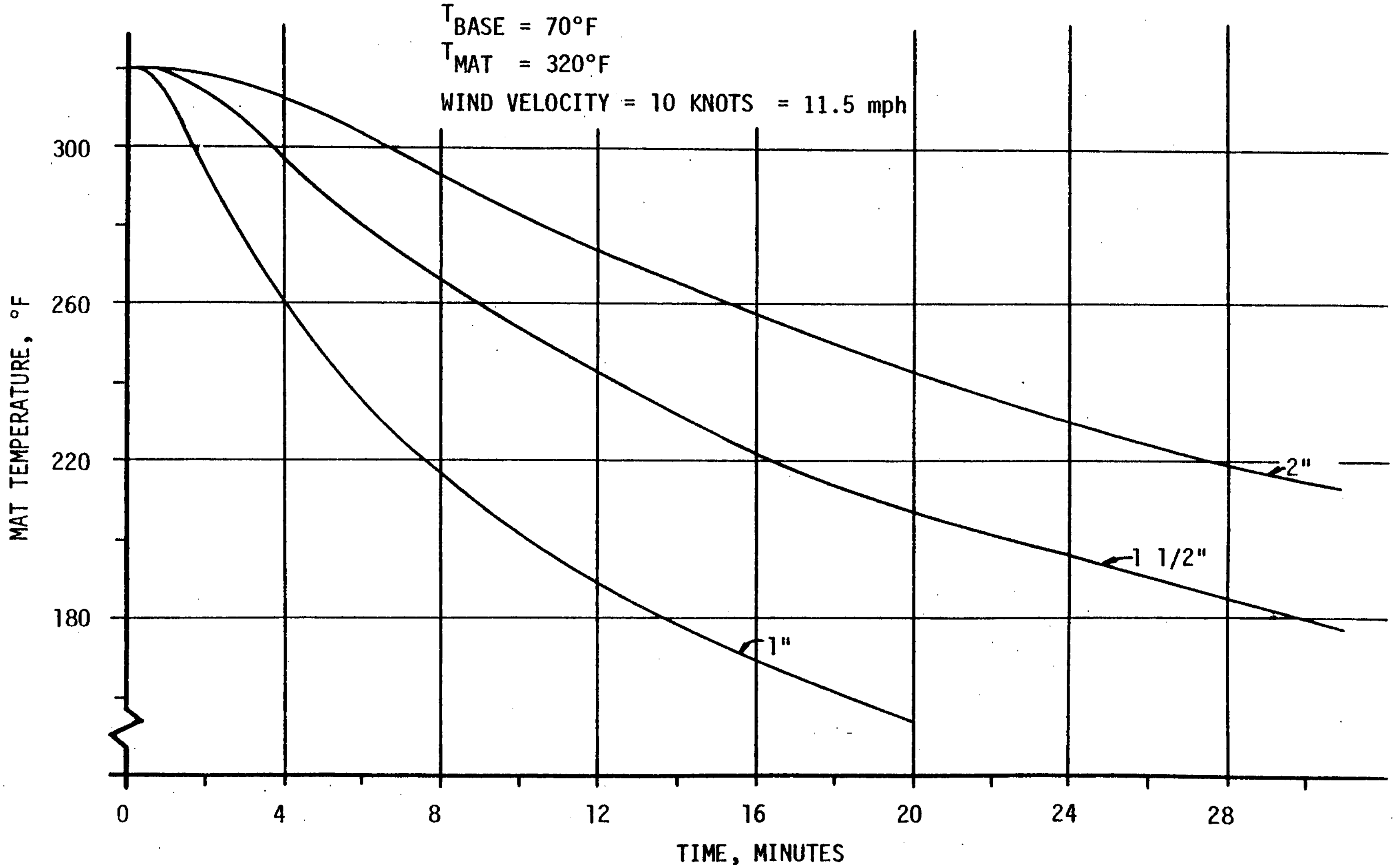


Figure B-5. Cooling Curves for Lightweight Aggregate Hot Mix ($T_{mat}$= 320°F).

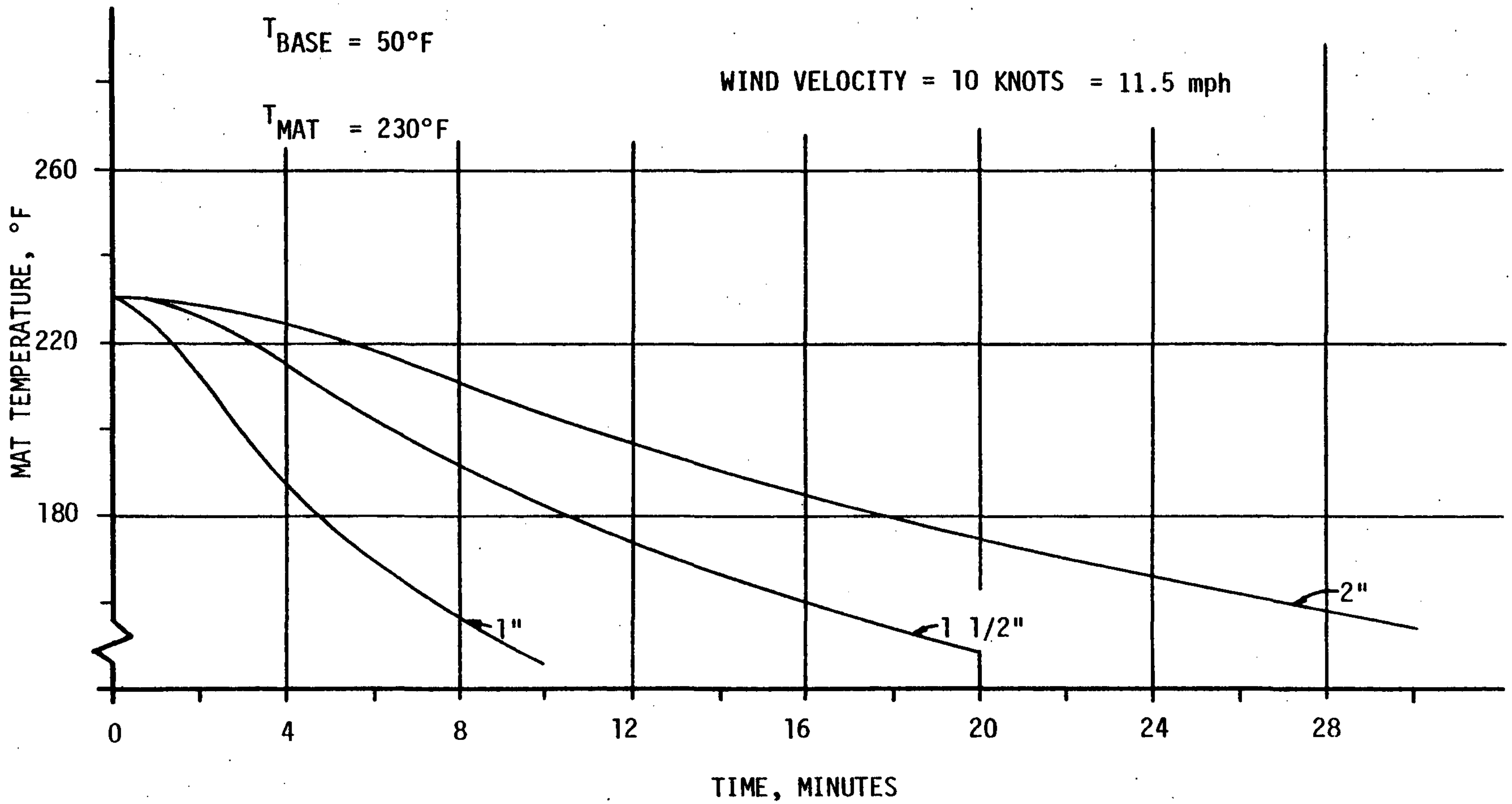


Figure B-6. Cooling Curves for Lightweight Aggregate Hot Mix ($T_{mat}$ = 230°F).

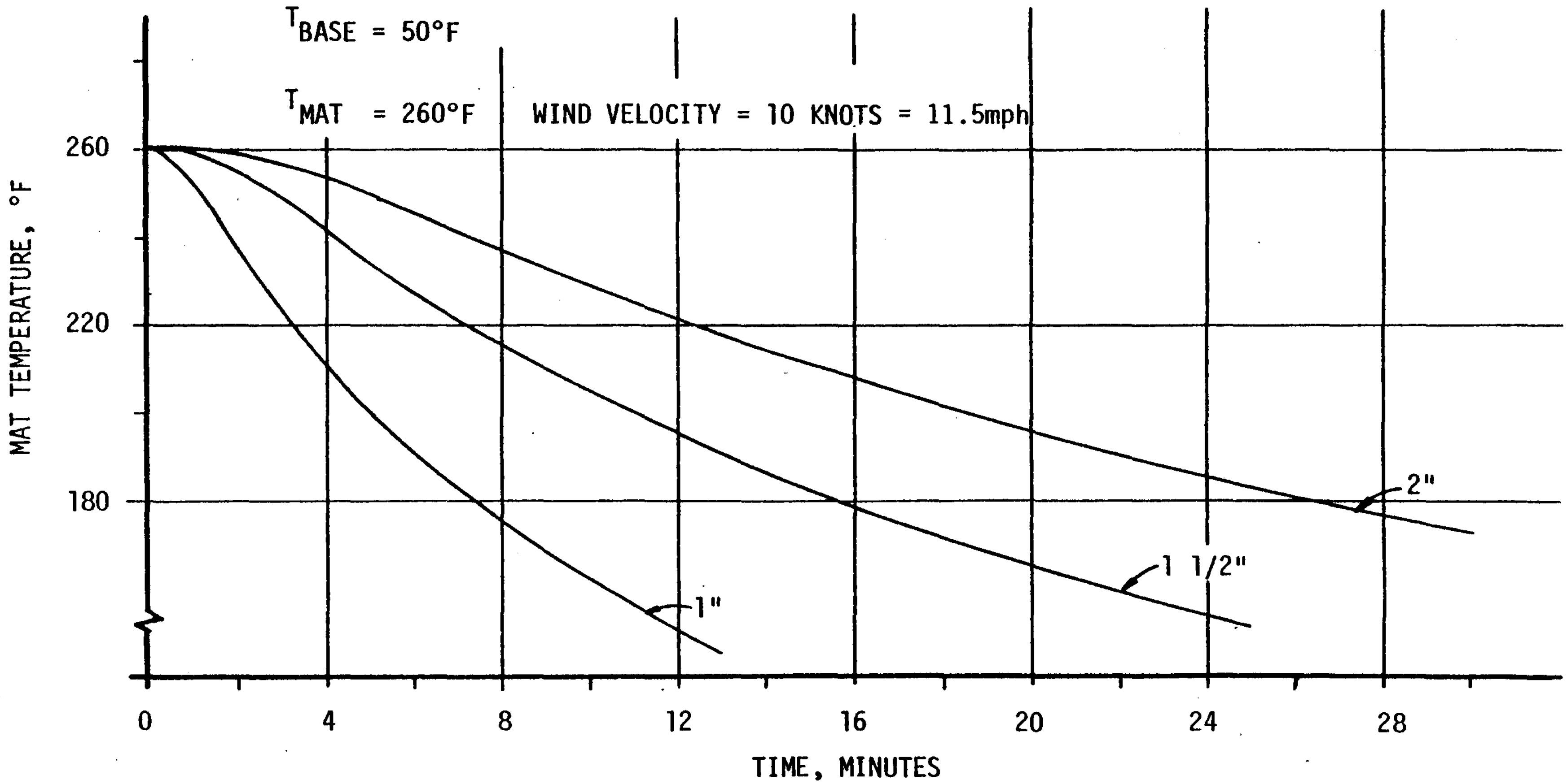


Figure B-7. Cooling Curves for Lightweight Aggregate Hot Mix ($T_{mat}$ = 260°F).

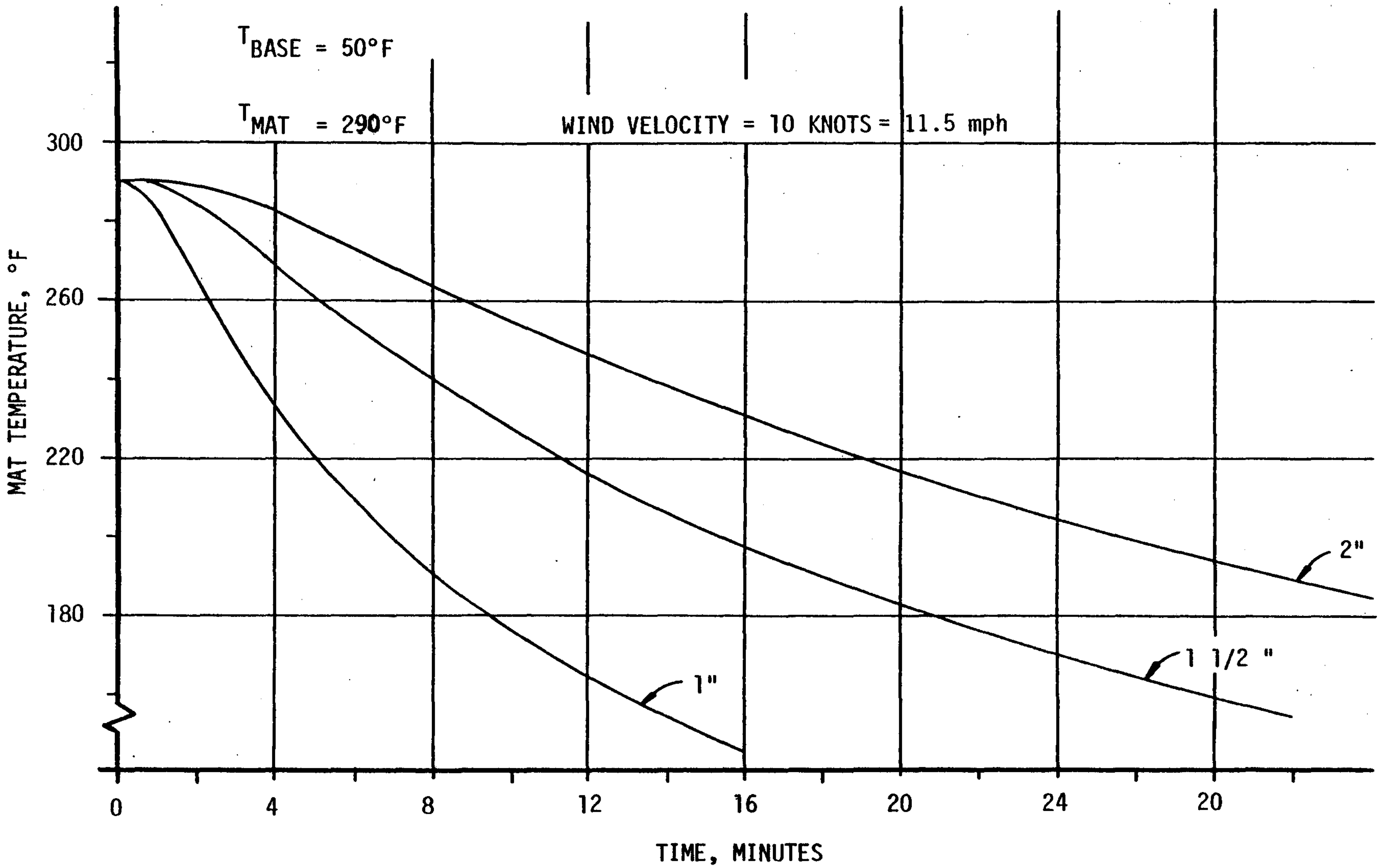


Figure B-8. Cooling Curves for Lightweight Aggregate Hot Mix ($T_{mat}$ = 290°F).

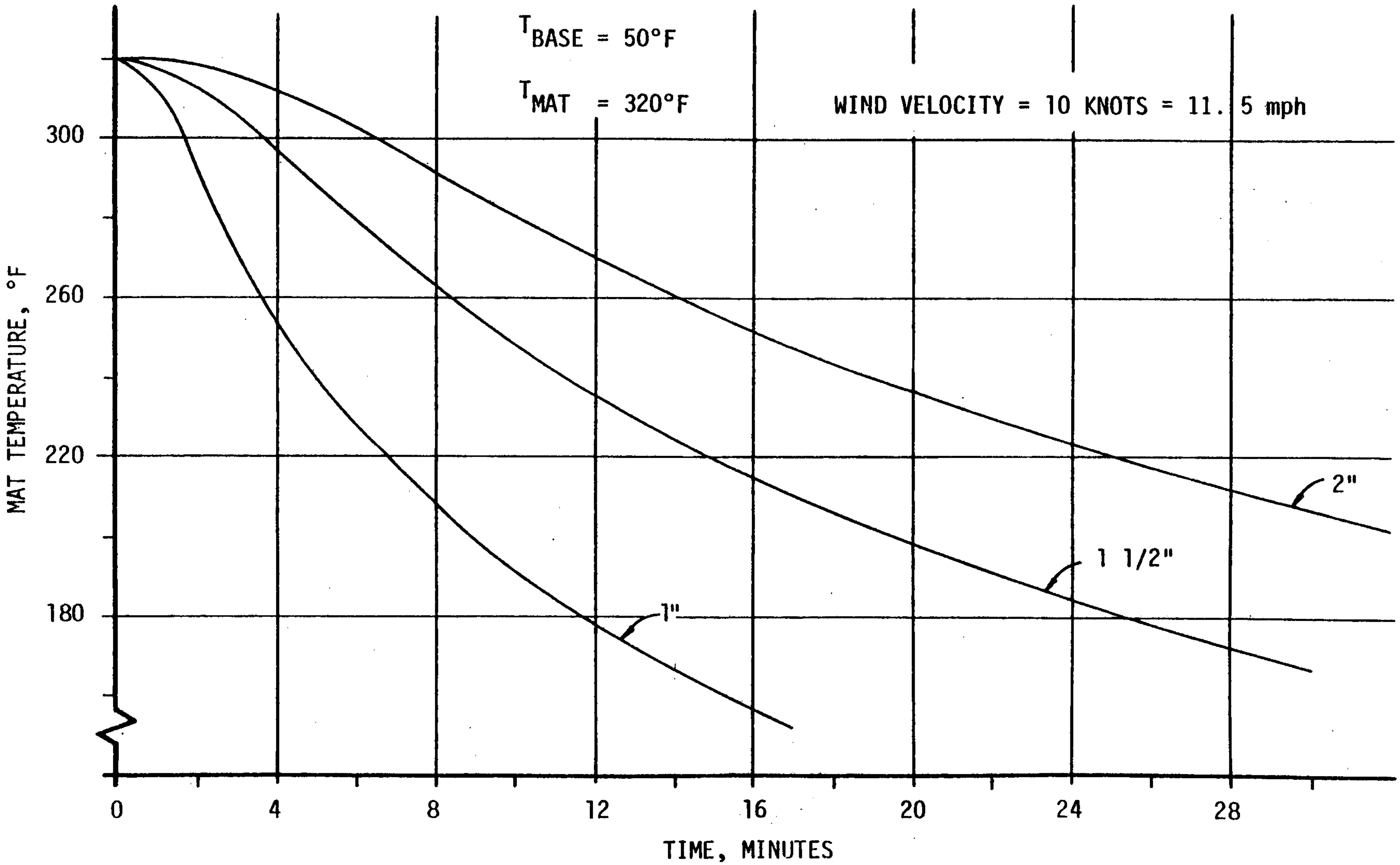


Figure B-9. Cooling Curves for Lightweight Aggregate Hot Mix ($T_{mat}$ = 320°F).

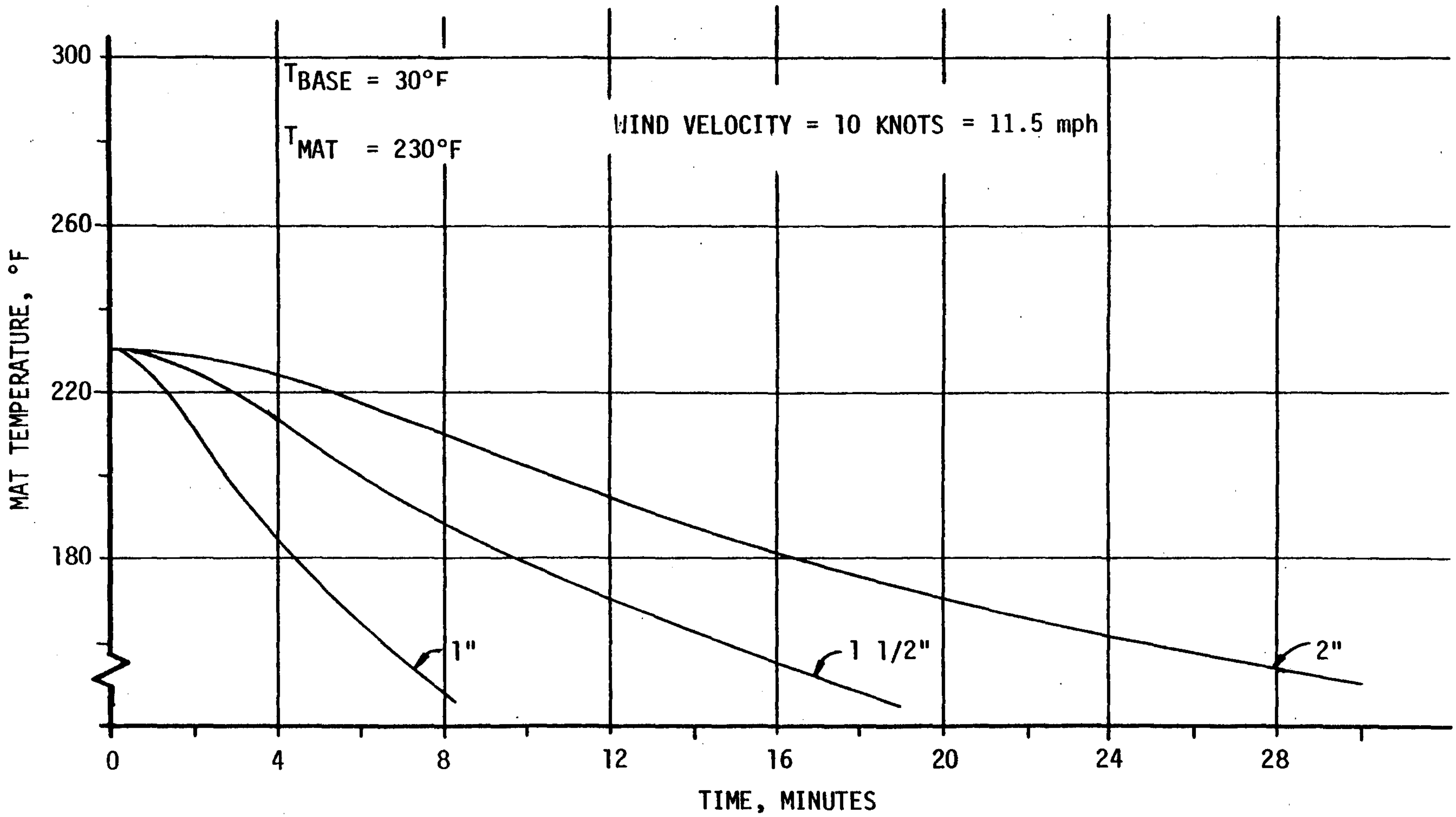


Figure B-10. Cooling Curves for Lightweight Aggregate Hot Mix ($T_{mat}$ = 230°F).

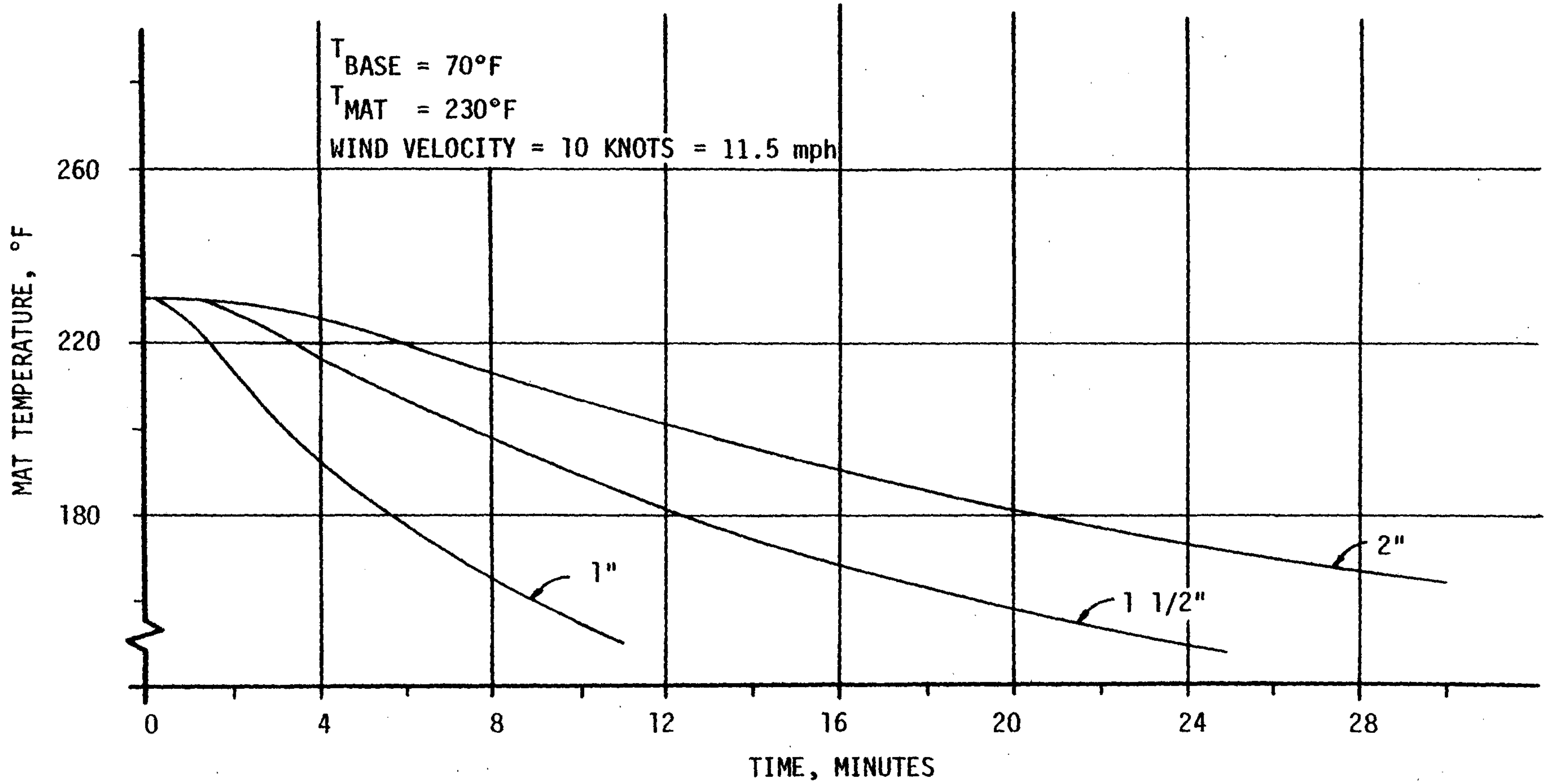


Figure B-2. Cooling Curves for Lightweight Aggregate Hot Mix ($T_{mat}$ = 230°F).

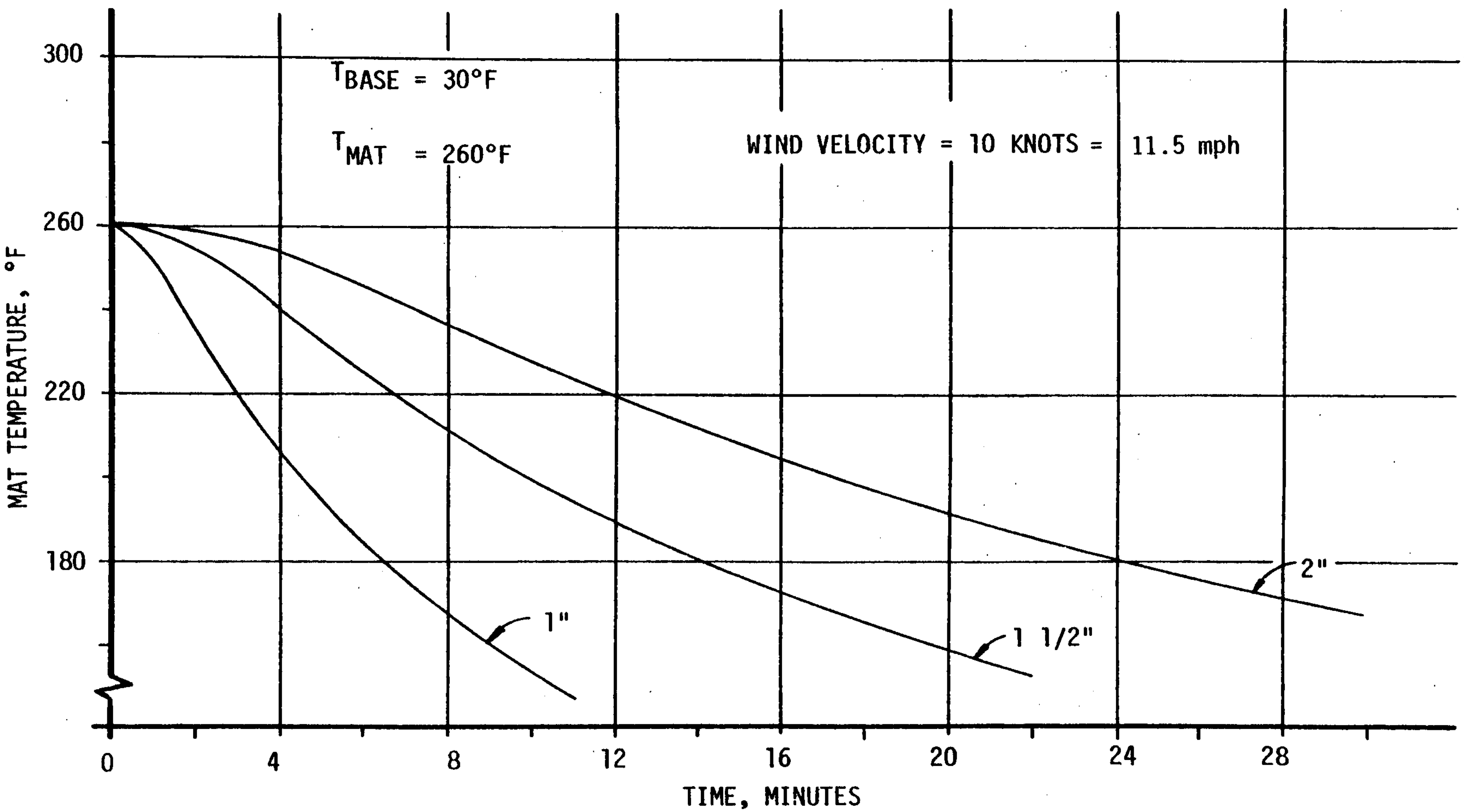


Figure B-11. Cooling Curves for Lightweight Aggregate Hot Mix ($T_{mat}$ = 260°F).

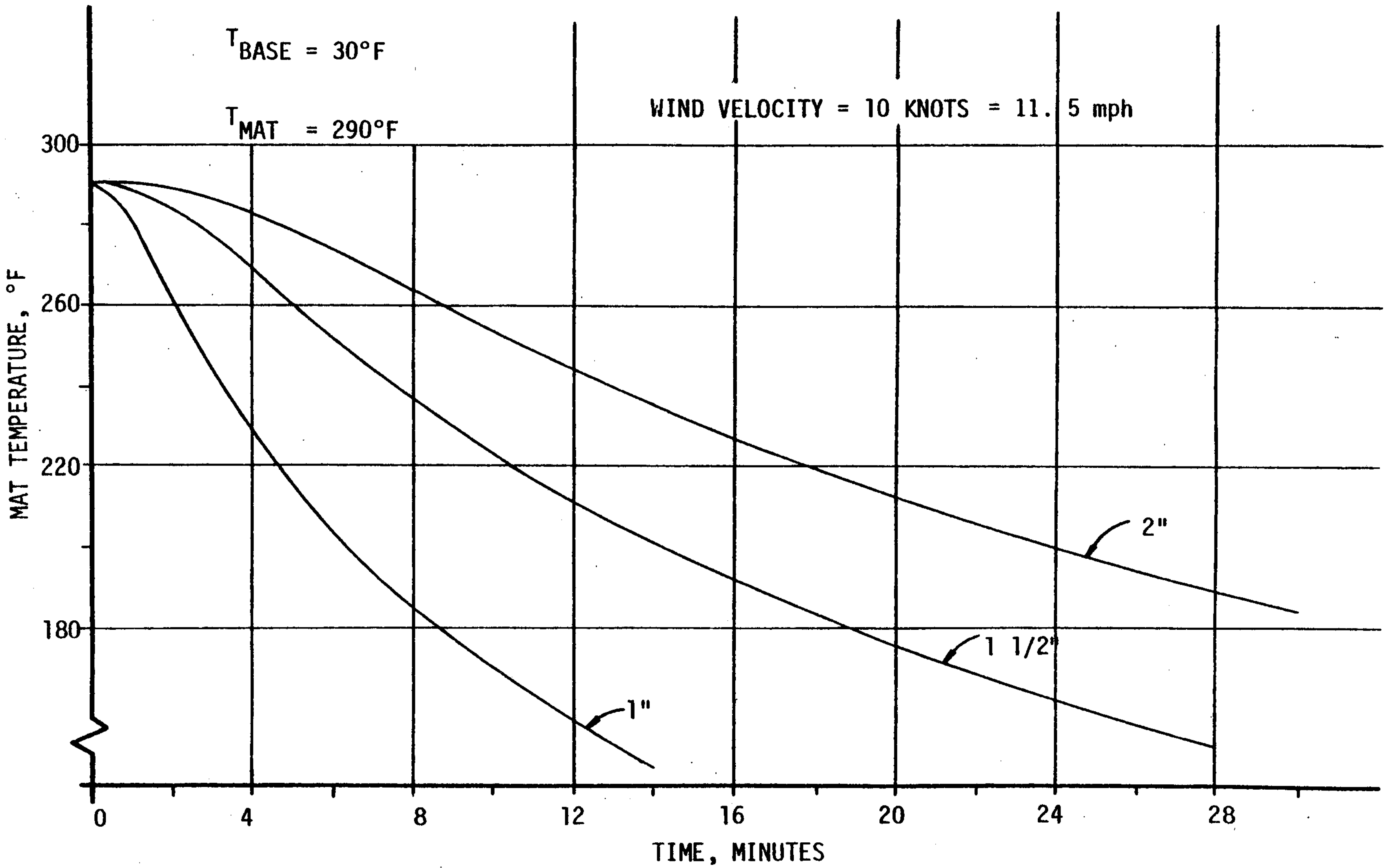


Figure B-12. Cooling Curves for Lightweight Aggregate Hot Mix ($T_{mat}$= 290°F).

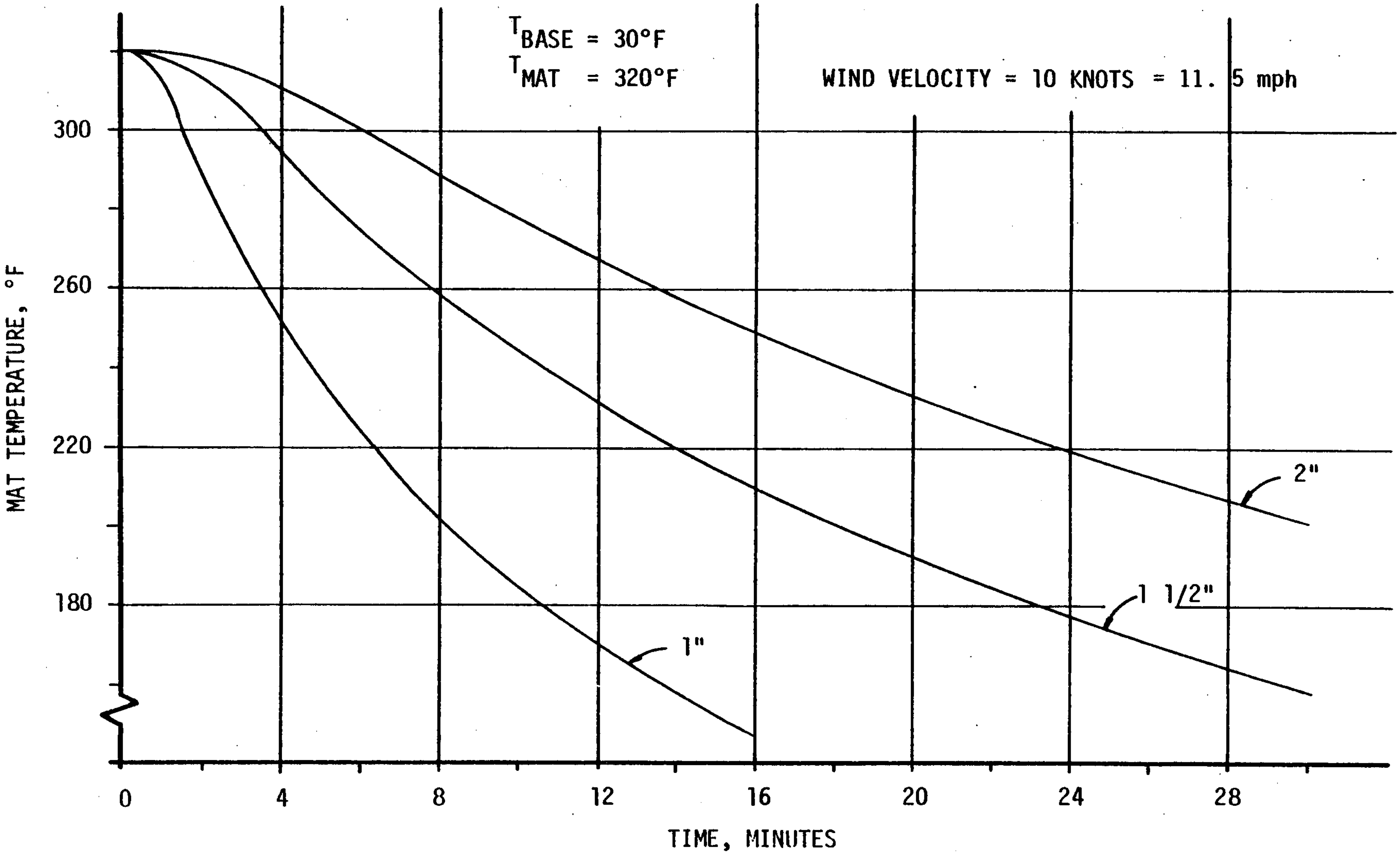


Figure B-13. Cooling Curves for Lightweight Aggregate Hot Mix ($T_{mat} = 320^{o}F$).