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Predicted Affinity Ratio between Asphalt Binder and Aggregate

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ABSTRACT

Affinity is a term used to describe the amount of the adhesion bond between asphalt binder and aggregate. Adhesion force may be used as indicator to the amount of energy or work required to breakdown the adhesive bond between asphalt binder and aggregate. In order to study affinity between asphalt binder and aggregate, a modified device is manufacture locally similar to Rolling Bottle Test (RBT) to Predicted the degree of affinity between asphalt binder and aggregate; taking into consideration mineral composition with physical properties of asphalt binder to measure required force to separate asphalt binder from aggregate surface. In this study, suggest new parameters to represent the stripping or affinity phenomena (affinity and stripping ratio) and the time required to make balance between them.

From the experimental work result, the affinity ratio of aggregate brought from Dohuk region was 52 % after 24hr of rolling time period which is less than other type because of its mineral composition (high percent of calcite and dolomite which increase ability to resist stripping), pore size and stiffness of aggregate particle. In other hand, the stripping ratio of aggregate brought from al-Taji quarry was 80% after 24hr of rolling time which represent worse case in affinity of aggregate-asphalt binder system due to increased percent of quartz in mineral composition (greater than 80%) and so reduced ability of aggregate to resist stripping

Keywords: Affinity between aggregate and asphalt binder, Stripping ratio, Affinity ratio and Rolling Bottle.

تنبأ نسبة الأنجذاب بين الرابط الاسفلتي والركام

الخلاصة

التقارب هو مصطلح يستخدم لوصف مقدار قوة التلاصق بين رابط الإسفلت والركام. يمكن استخدام قوة التصاق كمؤشر لمقدار الطاقة أو العمل المطلوب لتفكيك قوة التلاصق بين رابط الإسفلتي والركام. من أجل دراسة نسبة التقارب بين رابط الإسفلتي الركام ،تم تصنيع جهاز معدل محليًا مشابه لجهازفحص دوران الزجاجة (RBT) لتقدير درجة التقارب بين رابط الإسفلتي والركام ؛ مع الأخذ في الاعتبار تكوين المعادن مع الخصائص الفيزيائية للرباط الإسفلتي لقياس القوة المطلوبة لفصل الرابط الاسفلتي عن الركام. في هذه الدراسة اقترحت مصطلحات جديدة لتمثيل ظاهرة التعرية أو التقارب هي (نسبة التقارب والتعرية) والوقت اللازم لتحقيق التوازن بينهما.

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من خلال نتائج الفحص التي تم التوصل إليها، كانت نسبة تقارب للركام من منطقة دهوك بنسبة 52٪ بعد 24 ساعة من فترة الدوران اكثر من النوع الآخر بسبب تركيبتها المعدنية (نسبة عالية من الكالسيت والدولوميت التي تزيد من القدرة على مقاومة التعرية) ، وحجم المسام و صلابة الجسيمات الكلية. من ناحية أخرى، كانت نسبة التعرية للركام من مقلع التاجي 80٪ بعد 24 ساعة من وقت الدوران والتي تمثل حالة أسوأ في تقارب نظام الربط بين الأسفلت والركام بسبب زيادة نسبة الكوارتز في تكوين المعادن (أكبر من 80٪) وبالتالي انخفاض قدرة التلاصق على مقاومة التعرية.
الكلمات الرئيسية: التقارب بين الركام والرابط الاسفلتي، نسبة التعرية، نسبة التقارب ودوران الزجاجة.

1.INTRODUCTION

Affinity Phenomena between aggregate particles and asphalt binder can be defined as the amount of bond energy between asphalt binder and aggregate. Moisture damage is recognized by reducing in affinity between aggregate and asphalt binder and also the primary cause of pavement distress. Moisture damage can be characterized by adhesion failure between asphalt and aggregate **Kennedy, et al., 1982, Fromm, 1974, Majidzadeh, and Brovold, 1968 and, Tunnicliff and Root ,1982**. Asphalt binder-aggregate interaction have significant impact on performance of asphalt pavements mixture. It depends on various physical and chemical characteristics that determine the strength of the affinity bond between the two materials due to the separation or stripping of the asphalt binder coating from the aggregate surface, is caused by the action of moisture at the asphalt binder-aggregate interface, **Figueroa, et al., 2013**. The resistance of the adhesive bond to moisture damage relates to surface charge, polarity, porosity, type of adsorption sites and surface energy of the aggregate surface. These characteristics are directly defined by the constitutive minerals, **Bagampadde, et al., 2005** and therefore vary significantly between different rock types. The chemistry aggregate has been shown to be much more influential than asphalt chemistry for both adhesion and sensitivity to water**, Curtis, et al., 1993**; who evaluated asphalt-aggregate interactions in terms of adsorption and desorption isotherm behavior. The study explained also the asphalt binder components is most effective parameters on the affinity for the aggregates also tended to have the highest sensitivity to water. Based on the study conducted by, **Fromm, 1974**, moisture damage is mainly characterized by the adhesive failure between asphalt binder and aggregates. Adhesive failure is primarily a result when asphalt binder coatings the aggregates is displaced by water or moisture, and a phenomenon referred to as stripping becomes visible in the asphalt mixtures. Water or moisture penetrates between the asphalt binder films and aggregates surface, breaks the adhesive bond and strips the asphalt binder from the aggregates surface due to higher affinity of some aggregates to water or moisture than to the asphalt binder. Stripping phenomena is a complex phenomenon based on the physical and chemical properties of the asphalt mixtures such as chemical composition of asphalt binder and aggregates, aggregates mineralogy and surface characteristics, and compositional characteristics and quantity of filler. **,Alhaddad, and Khalid, 2015**;establish the criteria and procedures for the proposed adhesion test method in terms of test setup and apparatus, specimen preparation, testing and data analysis; and study different parameters (binder thickness, aggregate types, rate of applied load, test temperature and conditioning procedure) on the maximum tensile bond strength and tensile energy required to produce failure. **, Abedali, et al., 2016**; develop and establish simple practical and reliable monotonically- loaded laboratory adhesion test method for direct measurement of the adhesive bond strength of asphaltic material and aggregate.

2.OBJECTIVE OF THIS RESEARC.

The objectives of this work can be summarized as:

- Determining the affinity ratio between asphalt and aggregate.
- Predicated residual asphalt binder covering the aggregate.
- Study stripping phenomena with different condition.

3.EXPERMENTAL WORK.

3.1 Material

The materials which have been employed in experimental part of this study are:

- Asphalt cement in this work was used with penetration grade (40-50) brought from Al-Durah refinery in Baghdad. The physical properties and tests of asphalt cement used are shown in the **Table 1.**

Table 1. Physical Properties and Tests of Asphalt.

Property	ASTM Designation	Penetration grade 40-50	
		Test Result	SCRB (R/9, 2003)
Penetration@ 25 ^{o}C,100 gm.5 sec	D5/D5M - 13 (0.1mm)	43	40-50
Softening Point (Ring and Ball Temp)	D36/D36M − 2014 (^{o}C)	51	52
Ductility @25 ^{o}C, 5 cm/min,	D113/2007 (cm)	145	>100
Flash Point	D92/2016b (^{o}C)	279	>232
Specific Gravity	D70-2009e1	1.04	1.01-1.05

These tests are accomplished by National Center for Construction Laboratories and Researches in Baghdad.

- several types of aggregate brought from different regions of The properties of aggregates and asphalt cement are evaluated by using traditional tests and the results obtained are matched with the Specification Cooperation of Roads and Bridge SCRB R/9, 2003. The mineral composition and porosity of aggregates shown in **Table 2.**

Table 2. Mineral Composition and Porosity of Aggregates.

Aggregate	Mineral composition	Porosity
S1	Calcite 54.7% + Dolomite 36.6%	0.57
S2	Calcite 98.3% + Quartz 1.7%	9.11
S3	Calcite 98% + Carbon Graphite	1.06
S4	Quartz 80.3% + Calcite 11%	0.55

Where; S1; agg. from Dohuk region, S2; agg. from Karbala region, S3; agg. from Erbil region and S4 ; agg. from Al-Taji quarry.

These tests accomplished by Germany Laboratory in Earth Science Dept. of Baghdad University.

3.2 Rolling Bottle Method

The Rolling Bottle Test is a qualitative test used to evaluate the affinity between aggregates and asphalt binder on loose mix, according to the standard procedure of **European specification EN 12697-11,** three glass bottles for each stone material, filled with 150g of aggregates coated with asphalt binder and distilled water. The device that used in this work is manufacture locally with rotation speed 60 (round* min-1) with an accuracy of ± 10 % which meets all specification and according to **EN-12697-11**; as shown in **Plate 1.** The specimen preparation of the test was as below:

- Aggregate

  1- Wash 600g of sieved aggregate (which is passing sieve 11.2 and retain on sieve 8mm as required of EN 12697-2).

  2- Place the aggregate in ventilated oven set (110°C) until dry to constant mass.

  3- Take 510g of aggregate in to mixing bowl and allow to heat of mixing temperature

- Asphalt cement

Pour the asphalt cement in to metal container and allow to heat in oven until mixing temperature.

The mixing temperature is 175°C (mixing temperature by EN-12697/2016) and the asphalt cement quantity is 3% (by weight of mix) for the 8/11 mm aggregate and it is equal 16g.

After 6, 12, 18 and 24 hours the aggregate particles were emptied from the glass bottle into a test bowl filled with water and the affinity and stripping ratio was visually investigated by two operators.

Plate 1. Three Bottles in Manufacturer Rolling Machine.

4. ANALYSIS AND DISCUSSION OF THE RESULTS.

The result obtained from rolling bottle test explained the degree of susceptibility of forth types of aggregate to stripping phenomena. In the other hand asphalt binder properties have the same impact because of using the same asphalt binder with all types of aggregate. Before starting analyzing the results the limestone rock appears is good to resistance of stripping but quartzite rock appears is almost fair, Cordon**, 1979**. The aggregate coating (affinity parameter) can be used to describe the affinity phenomena as percentage of remaining asphalt binder coating the surface of the aggregates which determine by visual estimation of the operators, If this percentage equal to 100% that mean fully coated (More affinity) and if equal to 0% explain fully stripping (separation of asphalt binder from aggregate surface) (Less affinity) and so if this percentage in between that mean degree of asphalt binder separation. The stripping ratio of asphalt binder from aggregate (SR) Can be calculated as Eq. (1)

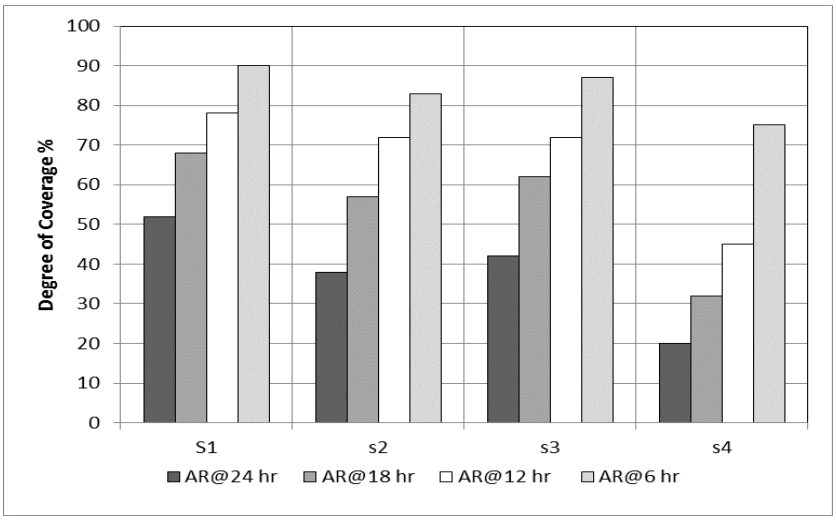
$$SR = 100 - AR \quad (1)$$

Where:

SR: Stripping ratio.

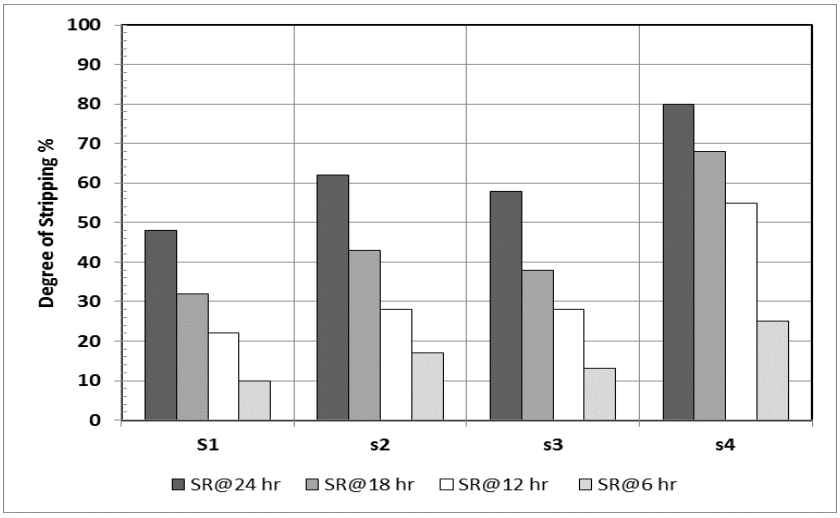
AR: Affinity ratio.

The experimental results for different types of aggregates with change test period times ranging between 6 to 24 hr are shown in **Fig. 1 and 2.**



Notes: AR is Affinity Ratio.

Figure 1. Degree of Asphalt Coverage of Aggregates after 24hr period of Rolling Test.



Notes: SR is Stripping Ratio.

Figure 2. Degree of Stripping of Asphalt after 24 hr period of Rolling Test.

All types of aggregate before start testing had fully coated with asphalt (high affinity parameter) and without percentage of stripping. When rolling time period of test increased the percentage of coating decrease subsequently percentage of stripping increased, but with different quantities along the types of aggregate.

The aggregate type S1; explained high affinity ratio subsequently low stripping ratio after 6 to 24 hours of rolling than other types that mean this aggregate have good resistance to stripping

(excellent affinity with asphalt binder). Aggregate S2 and S3; showed good and almost the same susceptibility to water. For 24hr test period affinity ratio were S2=38% and S3=42% as shown in previous figures, their affinity parameter are almost similar. The mineral compositions of these types are calcite (limestone). Limestone rock may be a great to opposing stripping on basic earth metals in the limestone copartner determinedly for the asphalt parts case in point carboxylic acids to form basic earth salts, and the bonds produced are not dissociated basically by water considerably at an high pH value , so that in this case those adsorption is solid due to those insolubility of the basic earth salts framed between the limestone and acids of bitumen.**, Yoon, and Tarrer, 1988**.also limestone had low surface area are and a good pore volume if comparted with granite or dolomite.

In other hand, Test confirmation reveals that the limestone aggregate under barbarous water treatment the external surface of aggregate breaks for starting with primary body, carrying the asphalt binder with it. **,Podoll, et al., 1991**. The aggregate type S4; explained satisfactory affinity ratio after 6 hours of rolling time but when the test continue the stripping ratio increases quickly subsequently affinity ratio decreases into unacceptable percentage 20% after 24 hr since the Norwegian specification limits the minimum degree of coverage after 48 hours to 25% **,Statens Vegvesen, 2014**, the mineral aggregate S4 combined with the asphalt binder used in this study, would be rejected.

In order to estimate the suitable time of rolling test to make equilibrium or balance between coating and stripping. The Microsoft excel used to predicate best fit equation to simulate the phenomena under study (affinity or stripping). The fitting analysis explain that the power trend is the best one as show in **Fig. 3 to 6.** The suitable time to make balance can be defined as the time required for affinity ratio equal to stripping ratio.

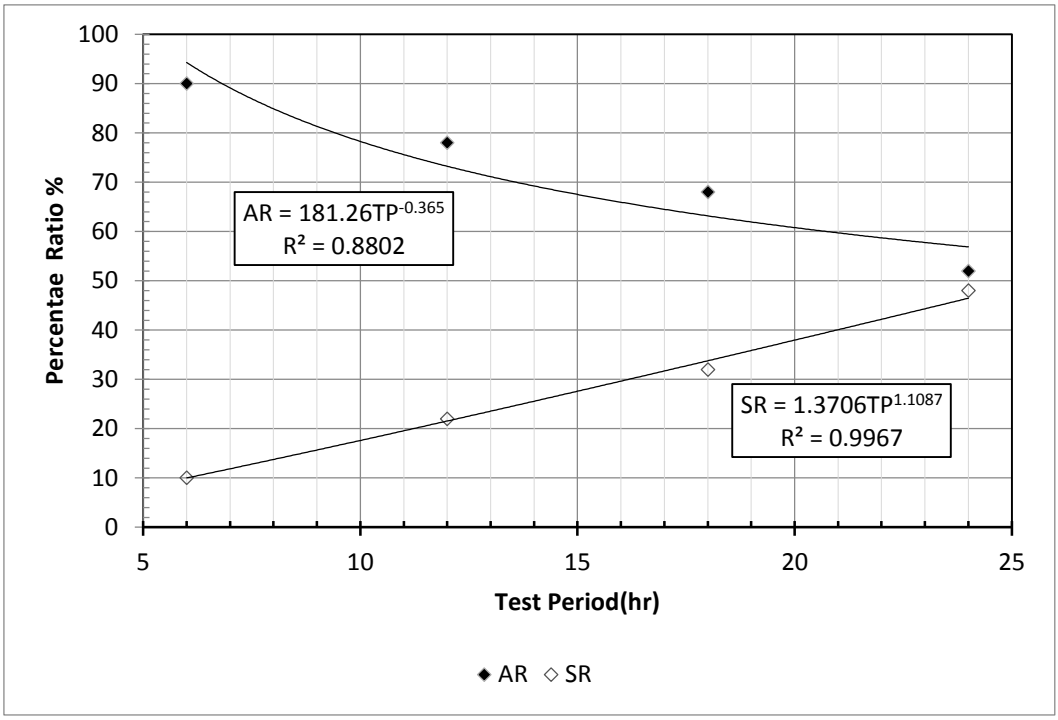


Figure 3. Relationship between Percentage Ratio and Time of Rolling for Aggregate Type S1.

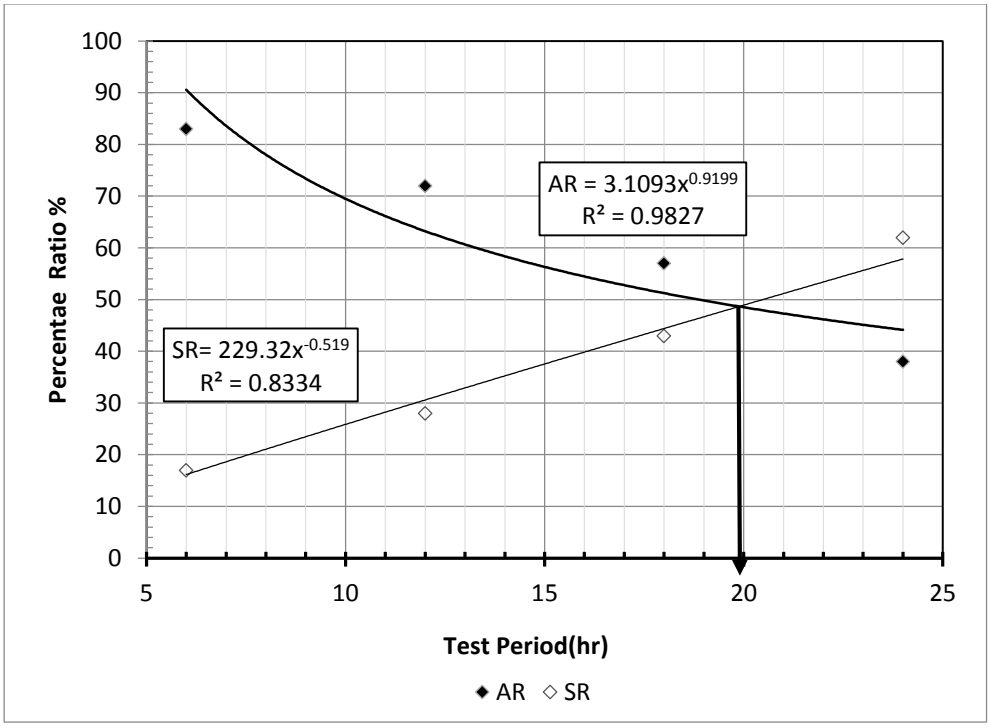


Figure 4. Relationship between Percentage Ratio and Time of Rolling for Aggregate Type S2.

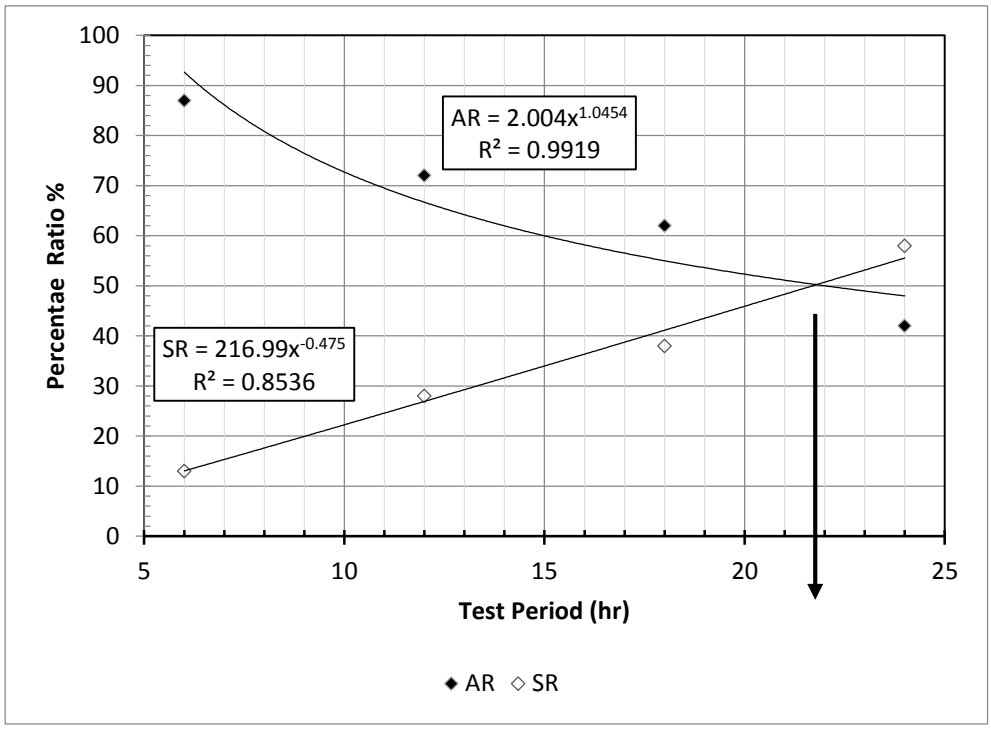


Figure 5. Relationship between Percentage Ratio and Time of Rolling for Aggregate Type S3.

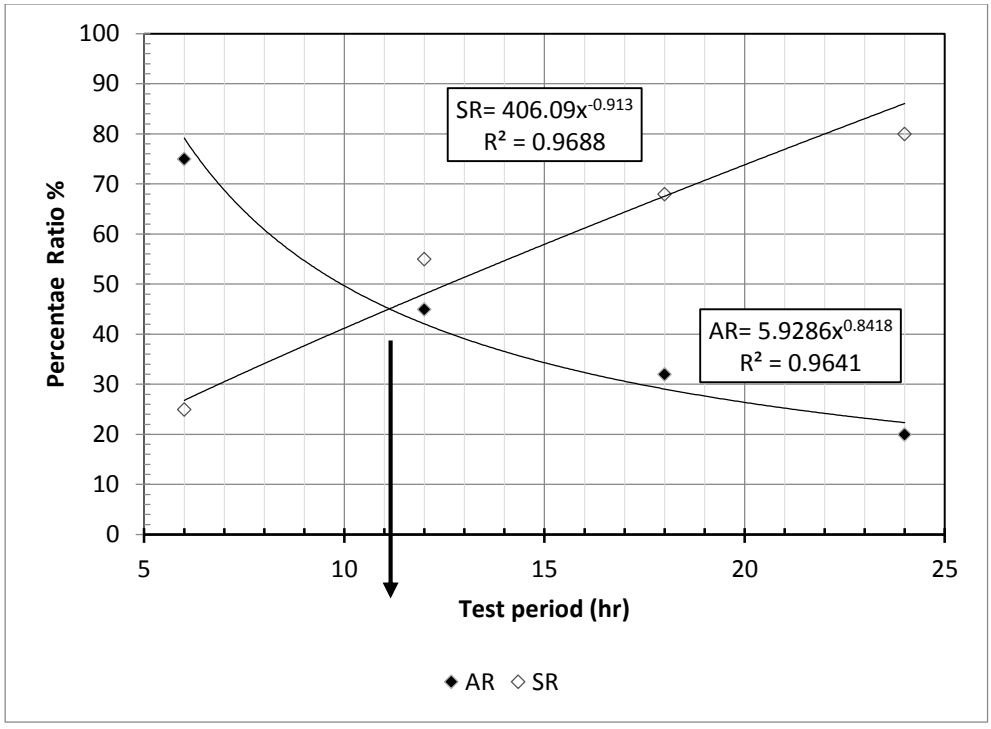


Figure 6. Relationship between Percentage Ratio and Time of Rolling for Aggregate Type S4.

The aggregate type S1; shows good resistance to strip; from equations of **fig.3** and has approximately the required time to make balance is 27.5 hr of rolling time period for stripping ratio be equal to affinity ratio. The aggregate type S2 need approximately 20hr of rolling time period for stripping ratio be equal to affinity ratio. The aggregate type S3 need approximately 21.5hr of rolling time period for stripping ratio to reach the affinity ratio. The aggregate type S4 need 11hr of rolling time period for stripping ratio to reach affinity ratio.

5.CONCLUSION.

Within the limitation of test and materials used in this study, the following conclusions can be introduced:

1- Time of immersion of aggregate and asphalt binder on water have a main role on moisture damage.
   The rolling time of Rolling Bottle Test increase the degree of asphalt binder covering the aggregate decrease.
2- Affinity ratio and stripping ratio are practical parameter can be used as indicators to estimate the failure types (adhesion or cohesion) to represent the quality of the aggregate type by their percentage with respect to time of rolling.
3- High affinity ratio of aggregate brought from Dohuk region was 52 % after 24hr of rolling time period than other type because of its mineral composition (high percent of calcite and dolomite which increase ability to resist stripping), pore size and stiffness of aggregate particle. In other hand, high stripping ratio of aggregate brought from al-Taji quarry was 80% after 24hr of rolling time which represent worse case in affinity of aggregate-asphalt binder system due to increased percent of quartz in mineral composition (greater than 80%) and so reduced ability of aggregate to resist stripping.
4- The suitable time required to make balancing between affinity and stripping is 27.5 hr for aggregate type S1 (more affinity aggregate) and 11 hr for type S4 (less affinity)

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