The wearing resistance of road aggregates and their impacts on the environment

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ABSTRACT
The excessive use of studded tires imparts wearing on road surfaces. This creates dust in dry conditions and produces fine materials in wet situations. The former results in air pollution and the latter brings about dirt on roads and fills road drainage systems.
In this work rutting which is caused by wearing action of studded tires have been measured on some roads located in cold and hilly regions. In addition to rutting, surface texture measurements were carried out. It was found that the properties of aggregate particles in the mix have the dominant effect in wearing resistance of mixes.
The potential tests that could determine the wearing resistance of aggregates have been evaluated and petrographical analysis was performed. Based on this latter and surface charge characterization, the above aggregates have been classified in different categories according to their qualities. Finally, the aggregate properties which resisted studded tires wear were determined and specific recommendations for aggregate type selection and wear testing were proposed.

1. INTRODUCTION

The highly trafficked roads that are located in cold and snowy regions experience significant damage due to the wearing action of studded tires. The major distress type that results from the phenomenon is rutting in the wheel path areas [1 and 2]. Visual observations in various sites indicated that wearing takes place on aggregates rather than the other components of mixes.
Aggregate failure is manifested into two separate phenomenons, namely, aggregate wearing and aggregate picking up from road surfaces [3].
In order to investigate the role of aggregate type in wearing of mixes different sites were selected. These were sites that had closed traffic numbers; located in similar geographical conditions; but had different aggregate types in their mixes. It resulted that in the sites where rather weak aggregates had been used, aggregate wearing was the main distress type. In contrast, in sites where hard and durable aggregates had been used, aggregate picking up was the dominant source of distress. The latter resulted to be due to debonding of aggregate particles. This itself could happen either through debonding between aggregate and bitumen or through breaking up of the binder due to the hammering action of the studds (Fig. 1).

2. STUDDED TIRE USE AND THE DRAWBACKS

The followings are the major key points why it is believed that the use of studded tires should be banned or their use should be limited:

2.1 - Main reasons why studded tires use should be limited:

- The limited potential benefits of studded tires under icy road conditions do not compensate for the significant adverse effects they create under other conditions.
- Studded tires create considerable health and road safety problems.
- Studded tire use is declining in different countries (e.g. Norway and Sweden)
- Studded tire use is banned in many countries (e.g. Minnesota, Wisconsin, Illinois and Maryland in the States and Holland, Belgium, Germany, and Japan).

2.2- Limited benefits of studded tires:

- Studded tires do not offer safety advantages in comparison to modern radial winter tires in road conditions which are either wet or dry for most of the time.
- Studded tires are only superior to conventional tires on glare ice near freezing temperatures; these road conditions occur only where no winter road maintenance is actually carried out.
- Any safety advantage is lost by even a small increase in speed.
- New lightweight studded tires cause only marginally less damage to the road surface than traditional studs and are less effective.

2.3- Health and road safety problems:

- Nuisance and health concerns.
- Increased noise levels.
- Create dust – impact on asthma and respiratory health.
- Give drivers a dangerous false sense of security.
- Studies have found that motorists with studded tires often drive faster under adverse conditions because of this overconfidence, which can create a greater accident potential.
- Cause road damage which contributes to serious safety hazards in all conditions
- Create ruts which fill with ice and water creating spray and hydroplaning.
- New light studs polish pavements, which reduces traction and creates a more slippery driving surface.
- Removes pavement markings.
- Cost of extra road maintenance resulting from pavement damage caused by studded tire use:
  - In Oregon: Cost estimated at US$70 million a year based on 1994 study.
  - Washington State DOT: spends US $10.5 million a year.
  - In Ontario, Canada: cost estimated at CD$39 million a year.

3. WEAR RUTTING

In the sites where wearing occurred, these resulted predominantly in “wear rutting” on the pavements (Fig. 2). By wear rutting it is intended to distinguish between this type of distress with that of “deformation rutting” which mostly occurs in hot climate areas rather than the cold and snowy zones. Table 1 reports the results of rut depth measurements in some winter sites. These were the sites located in various mountainous roads. The main difference in the mixes were actually the aggregate sources. The data are the results from sand patch testing on these sites (i.e. sites with mixes containing different aggregate types). In this table a parameter is defined as Texture Index (IT) which is the ratio of the following parameters on a road:

$$TI = \frac{\text{Texture depth in areas outside wheel path}}{\text{Texture depth in areas inside wheel path}}$$

In fact, TI helps in distinguishing between “aggregate wearing” and “stone picking up” from the road surfaces. In the site inspections, the following points were noted:

- Where TI<1 : Aggregate wearing was the main distress type on the road. In these sites sand patch values on the areas within the wheel paths domain were greater than in the areas outside the wheel paths; and,
- Where TI>1 : Aggregate picking up from the road surface was the main source of distress. In these sites sand patch values in the inside wheel path areas were smaller than those in the outside wheel path areas. With reference to Fig. 1, the failures were either due to debonding between aggregate particles and the mix binder or actually due to the embrittlement of mix binder. This latter phenomenon might happen due to both combination of low temperature embrittlement and the hammering action of the studded tires.

Table 1- Measured texture depth in various winter road sites

Site No.	Rut Depth (mm)	Texture Depth (mm)		Texture Index (OWP/IWP)
		OWT	IWT	
1	6.5	2	1.6	1.25
2	8.5	2.1	1.9	1.1
3	3.7	1.6	1.8	0.89
4	7.5	2.5	2.2	1.14
5	3.2	1.4	1.7	0.82
6	9.7	1.4	1.2	1.17
7	4.0	2.3	2.45	0.94
8	8.5	2.3	1.9	1.21
9	6.0	2.1	2.4	0.87
10	5.5	1.8	1.6	1.12

Note: OWT= Outside wheel path, IWT= Inside wheel path

4. AGGREGATE ANALYSIS

Aggregate sources of the various pavement sites were recognized and the samples were collected for testing purposes. The actual pavement sites had typically the following characteristics:

- ✍ Studded tire problems were rather pronounced (i.e. had wear rutting problems),
- ✍ The sites were selected from different geographical areas (i.e. in flat and mountainous areas),
- ✍The pavements had rather closed ages (i.e. similar conditions); and,
- ✍ The aggregates used in their surfacing were from different sources.

A series of Los Angles Abrasion tests (LA) were performed on aggregate samples and the LA values were compared with the actual wear rutting values of Table 1. On performing this, no particular correlation was found between the LA abrasion values and road wear rutting. It was concluded that LA abrasion testing is not a proper test method for investigating the effects of studded tire wearing on aggregates. Although there are some Scandinavian tests that might better correlate the studded tire action (e.g. Ball Mill and SKR tests) because of lack in laboratory equipments these were not performed. However, full details of these tests could be found in standard specifications of these countries [e.g. ref . 4].
In order to investigate the characteristics of the above road aggregates a petrographic analysis was performed. This was mainly to determine the rock types and their mineralogy from analysing the respective aggregate particles. For this purpose macroscopic examination and trasmitted light microscopy techniques were applied.

4.1 – Crystalline Formation

In wear rutting, caused from aggregate wearing, the crystalline formation of the aggregate particles was suspected to be one of the major parameters to contribute wear, either positively or negatively. In fact, some aggregates had rather hard and compacted particles and some others were porous and had weak mechanical properties.
Samples that were taken from the sites, where these had little wear problems, showed to have distinct characteristics in the petrographical examination. The particles of these samples generally showed to have monolitic, dense, well compacted and homogeneous crystals. In contrast; the samples, taken from the sites that had severe wear rutting problems, showed to have porous particles or weak particles with fractured grains.
In order to categorise the aggregates for their crystalline formation, a model that was proposed by Anderson and Henry [5] was adopted (Table 2). In this table seven models are presented for the common aggregates that are used in road construction. For each model a brief description and grain formation sketch is presented. In this work, from the petrographical studies of the samples, these latters were categorised in this model and their position were determined in Table 2.
From the above table it can be seen that most of the aggregates were located within models 2 to 4; with some exceptions that laid in model 7. The samples that were positioned in model 7 were taken from the site numbers 6 and 8 in Table 1. In these sites greater wear rutting had been formed. In contrast, the aggregates that were categorized in model 2 were actually taken from sites 3 and 7 (Table 1), where the wear rutting values were the lowest among those in the other sites. Hence it resulted that this technique could be a valuable method for anlysing the aggregate wear characteristics.

4.2- Surface charge

Stone picking up problems are mainly bond failure between the aggregate particles and the bitumen binder which sticks them to road surfacing and other particles in the mix. It has been recognized that bituminous mixes containing lime, for example, show a high resistance to stripping. In these cases the enhanced bonding is attributed to the effects of a positive surface charge on the aggregats. Table 3 reports the surface charges of a variety of mineral aggregates, based on their silica contents [6]. Some aggregates have definite positive or negative charges and some are mixed (i.e. either slightly positive or negative, according to their minor constituent minerals). For this study, surafce charges were determined for each sample. Based on the mineral composition of the aggregates the results are shown in Table 3. It should be emphasized that their position in the chart is approximate, as their silica contents were not measured by a chemical composition analysis or X-ray testing but only were determined from petrographic examination which was performed on the transmitted light microscope.
With reference to Table 3, it can be noted that most of the aggregate particles that were examined in this study lay within the negative or mixed charged areas. This could be the other possible good reason for the wear rutting that have been occured in the investigated sites.

5. CONCLUSIONS

In evaluating some winter roads that suffered wear rutting under the wearing action of studded tires the following conclusions could be drawn:

1. Wear rutting were caused in two distinct different modes, namely aggregate wearing and aggregate picking up from the road surfaces.
2. Los Angles abbrasion test (LA) was found not to be a promising test for characterizing studded tire wear resistance of aggregates, as the correlation between LA and wear rutting in the field was found to be rather poor .
3. The petrographic studies that were based on macroscopic examination and transmitted light microscopy were found to be good techniques for predicting the wear resistance of aggregate particles under the action of studded tires.
4. Determination of the surface charge of aggregate particles, based on their silica contents, were also found to be a good method for predicting the bonding characteristics between bitumen and aggregate particles; although X-ray anlysis or chemical composition determination techniques would be more precise.
5. With regard to surface charge characteristics of aggregate particles, categorization of aggregates, based on their silica content, is also a proper method for predicting the bonding characteristics between bitumen and aggregate particles. The aggregates that were in the negative side charges had come from the sites with stone picking up problems. Hence, the use of these types of aggregates in studded tire prone sites should possibly be avoided.

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