

REAGGLOMERATION AS A CAUSE OF TREAD GROOVE CRACKING*

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INTRODUCTION

Groove cracking has always been a major cause of tire failure. The severity of the problem has varied, being particularly aggravated by the introduction of GR-S (SBR) in World War II. Improvements in tread design and in the rubber itself greatly alleviated the problem. However, the advent of turnpikes and high speed driving in the 1950's again accentuated groove cracking in passenger tires. Cracking has remained a problem in large truck tires.

Recently, elastomer changes have given promise of reducing the incidence of groove cracking. It is likely, however, that as long as tires are built, compounding or design changes will remain important factors in accentuating this problem.

Much has been written on the subject of fatigue and ozone cracking. These studies have for the most part dealt with measurements of crack growth and the actual physics of crack propagation. Powell and Gough¹ in 1945 suggested the possibility of crack initiation by grit particles at the surface of the rubber. They related the propagation of cracks to the stress conditions and tear properties of the bulk of the vulcanizate. Parkinson and Bloxham², also in 1945, demonstrated the poorer fatigue resistance of SBR in comparison with natural rubber vulcanizates.

An extensive review of flex-cracking mechanisms and of test procedures for studying cracking was published by Buist and Williams³ in 1951. Buist⁴ in 1953 demonstrated that crack growth was greatly accelerated at elevated temperatures, particularly in SBR. Using the unique method of high speed photography Gul and Vitnits⁵ in 1959 also studied the influence of temperature on cut growth in black loaded vulcanizates. They demonstrated that the rate of rupture decreased from 22° C down to -50° C and then increased again.

An extensive study of ozone attack on stretched vulcanizates was carried out by Braden and Gent⁶ in 1960. They showed that the propagation of ozone cracks is a function of the critical stress applied. The stored elastic energy is a more appropriate criterion if vulcanizates of different stiffness are compared.

Recent experiments at the Columbian Laboratories⁷ have demonstrated that cracks in carbon-rubber vulcanizates can be initiated by dry agglomerates of black. This effect is illustrated in Figure 1, in which a stock with a poor dispersion is shown before and after repeated stretching to 50% elongation.

The studies carried out in the present paper have approached the problem of tread groove cracking on the basis of what is happening to the rubber during tire operation. These observed changes as well as factors influencing them are discussed in detail.

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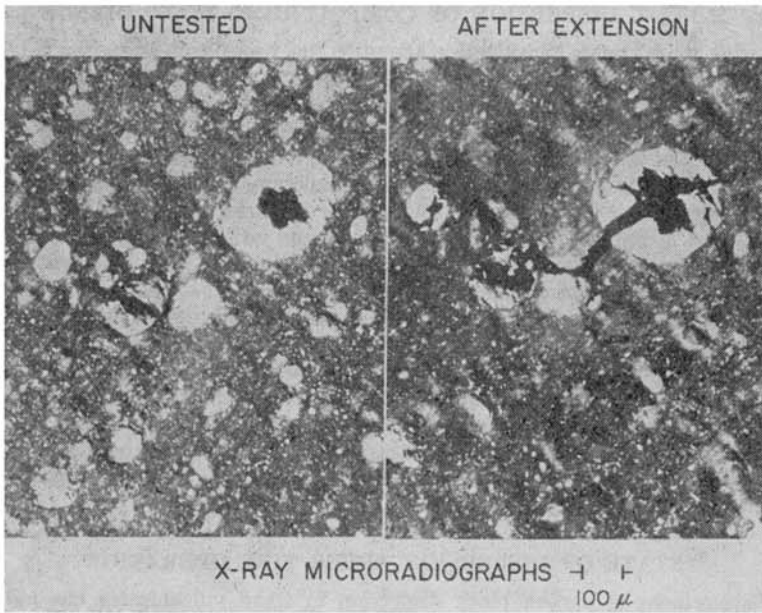


FIG. 1.—Crack initiation.

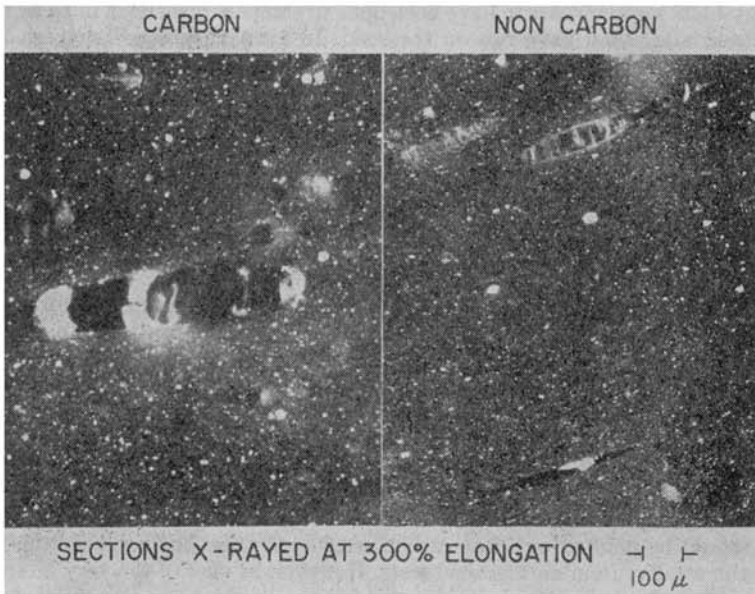


FIG. 2.—Pigment agglomeration in tire treads.

INITIAL DISPERSION OF COMPOUNDING INGREDIENTS

During recent years considerable attention has been focussed on the subject of the dispersion of carbon black in tread rubber. A number of authors^{8,9,10} have stressed the importance of producing a uniform distribution of black particles to achieve optimum vulcanizate properties. Considerably less effort has been devoted to studying the dispersion of compounding ingredients other than carbon black.

The relative weakness of dry pigment agglomerates is readily apparent through microradiographic examination of thin rubber sections under strain. This effect is illustrated in Figure 2 in which both carbon and non-carbon agglomerates have ruptured at an elongation of 300%. These as well as all other microradiographs shown in this paper are printed as negatives. Hence, all areas of relatively high x-ray absorption show up light in tone. Particularly dark regions around or within the pigment agglomerates represent actual breaks in the specimen.

A less common type of dispersion defect is illustrated in Figure 3. Shown here is an oil extended SBR-black vulcanizate exhibiting a streaky, uneven blending of polymer and compounding ingredients. The transparency of the streaks under the light microscope indicates a black loading considerably lower than normal. However, by microradiography the streaky areas showed high x-ray absorption due to large concentrations of zinc oxide.

STATE OF DISPERSION AFTER TIRE OPERATION

Measurement of carbon black dispersion in tread vulcanizates has failed to provide a good indication of cracking resistance. Although undispersed agglomerates of dry black may initiate cracks it appears doubtful that they are a serious factor in the propagation of cracks other than in extreme cases of poor dispersion. This is borne out by the fact that treads at a very high dispersion level have often cracked quite severely.

Very little work appears to have been done to compare dispersion in tread stocks before and after they have run on the road. In 1940 Parkinson¹¹ suggested that flocculation of black particles took place when unvulcanized stocks were allowed to stand for several days. The experiments of Bulgin¹² a few years later also suggested carbon flocculation in vulcanized stocks as shown by increased conductivity when the samples were heated. The rise in conductivity was particularly evident when the stocks were heated and flexed simultaneously indicating reagglomeration of the black particles to form conductive linkages.

The idea of a change in carbon black distribution occurring in a tread while in service has not appeared plausible. Yet, just such a phenomenon was observed in a recent tire test on a dynamometer. Shown in Figure 4 are light micrographs of an SAF-NR truck tread formulation before and after running 3600 miles on a dynamometer at normal load. The change in black dispersion is quite dramatic. Further testing up to about 14,000 miles failed to produce any further change in dispersion. Similar increases in the frequency of large carbon agglomerates, but to a lesser degree, were observed in an ISAF-NR tread stock as well as in several oil extended SBR compounds. All of the SBR treads showing the dispersion change originally exhibited uneven distribution of the type illustrated in Figure 3. It is interesting to note that the streaky appearance of these stocks was no longer visible after the tires had been tested.

It should be pointed out that carbon reagglomeration has not yet been found to exist in treads run in normal road tests. However, in view of the very interesting results obtained on the dynamometer, this is an area which appears worth looking into more closely in future studies.

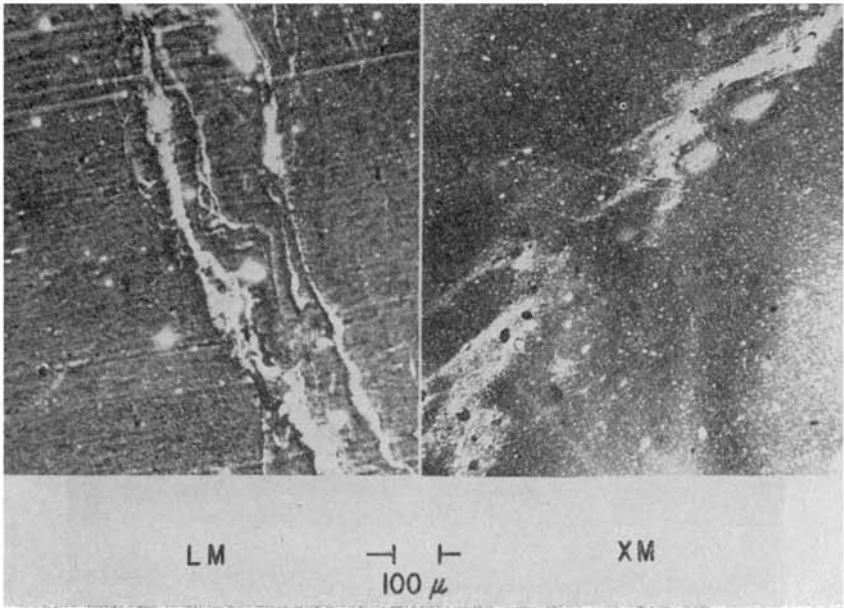


FIG. 3.—Uneven distribution, oil extended SBR.

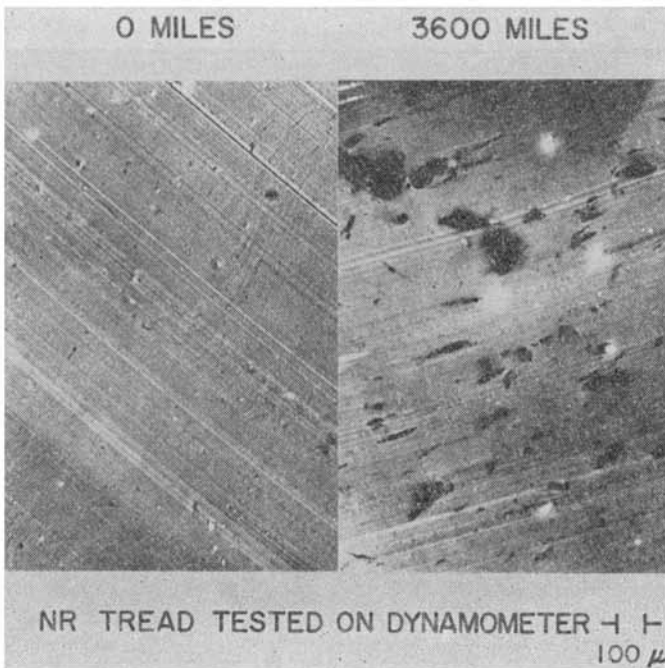


FIG. 4.—Carbon reagglomeration.

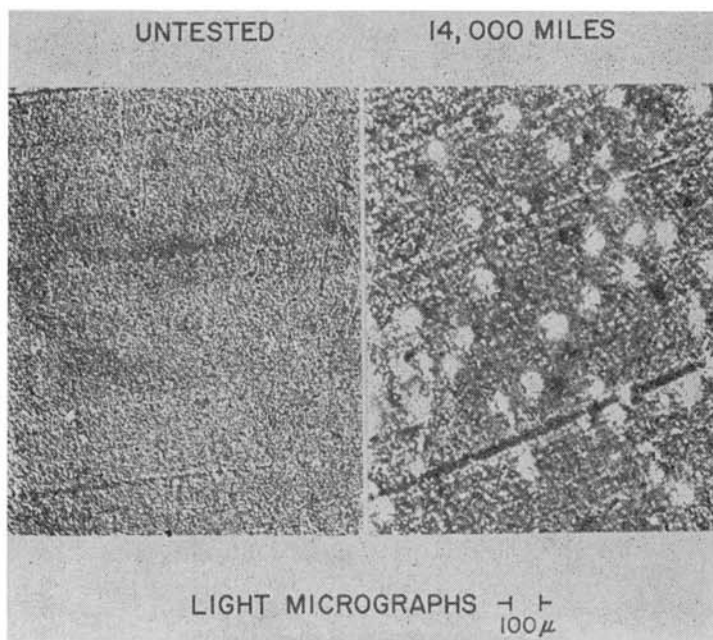


FIG. 5.—Non-Carbon reagglomeration.

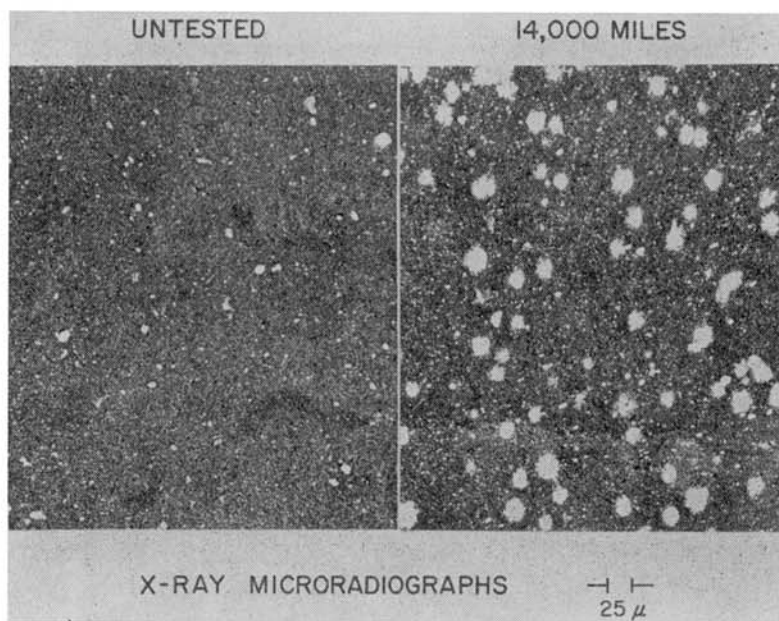


FIG. 6—Non-Carbon reagglomeration.

The remainder of this paper will deal with a phenomenon broadly termed "non-carbon reagglomeration". This refers to an actual physical rearrangement of compounding ingredients other than carbon black. The rearrangement occurs after vulcanization, during the time that the tire is in service. An example of non-carbon reagglomeration is shown in Figure 5 in which light micrographs of an oil extended SBR tread are shown with no mileage and after 14,000 miles on the road at speeds of 60-65 mph. The tested tread shows numerous light areas which at first glance appear to be holes. However, examination of the same stocks by microradiography show conclusively that these "light" areas are actually high in x-ray absorption (Figure 6). Inasmuch as the light microscope examination indicated lower carbon content for these reagglomeration areas it was concluded that they must contain relatively high amounts of some of the other compounding ingredients. In all probability it was thought that they were rich in zinc which would then explain their high opacity to soft x-rays.

Studies on a large number of road tested tread samples have indicated that non-carbon reagglomeration is a fairly common occurrence. A similar effect has occasionally been observed in untested tires. However, for the most part the high absorption reagglomeration areas are seen only in tires that have been run on the road for at least a few thousand miles. The total amount of time in service and severity of the test conditions both appear to be important factors in their formation.

Some different examples of reagglomeration in worn tire treads are shown in Figure 7. In sample "A" there is an actual linear alignment of the reagglomeration areas. Sample "B" shows a clustering pattern which has also been observed quite frequently. It will be noted that the reagglomeration areas in both of these samples tend toward a spheroidal shape. This is the most common form in which they have been found. However, in some cases a more irregular, dendritic appearance has been observed as shown in sample "C". In many instances areas have been observed which show a very high absorption nucleus surrounded by a more diffuse layer. This type of configuration is illustrated in Figure 8. In line with the recent work of Walters and Keyte¹³ it appears that the dense nuclei in these areas are zinc oxide and that the more diffuse fringes represent the formation of zinc stearate.

By means of ultrathin sectioning, it has been possible to examine some of the non-carbon reagglomeration areas directly in the electron microscope. In general, very dark, cloudy blotches were observed in the center of the individual reagglomeration areas indicating high electron scattering. Carbon loadings were low, as would of course be expected from the light microscope observations. A thin section of a single reagglomeration area is shown in Figure 9. In the lower left hand corner of this micrograph a "normal" area of black loaded rubber can also be seen. The outer perimeter of this particular reagglomeration area suggests the shape illustrated in sample "C" of Figure 8.

Employing the freeze-fracture replication technique used recently by Prestridge¹⁴ it was possible to study the internal structure of the reagglomeration areas in greater detail. In Figure 10, employing this method, a normal area of carbon black loaded rubber is compared to a non-carbon reagglomeration area. The latter region clearly exhibits cleavage planes showing a stepwise structure. Inclusions of what appear to be some smaller, discrete particles can also be seen.

Up to this point nothing has been said regarding the possible effects of reagglomeration areas in a tread stock. Employing the technique of examining thin sections under strain by microradiography a tendency toward weakness in the reagglomeration areas has been observed. A section from an oil extended SBR tread is shown in Figure 11, at a strain of 300%. The weakness of the areas in this micro-radiograph is quite apparent. The tendency of the reagglomeration areas to break

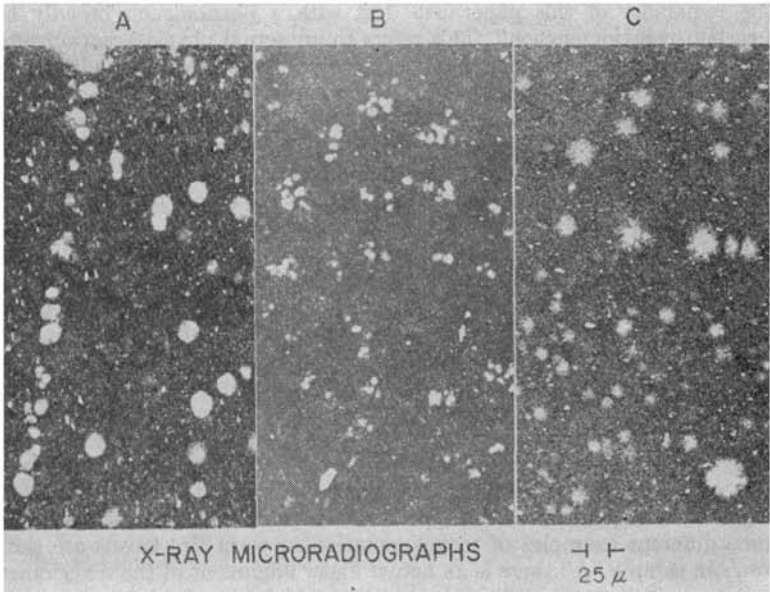


FIG. 7.—Different examples of reagglomeration

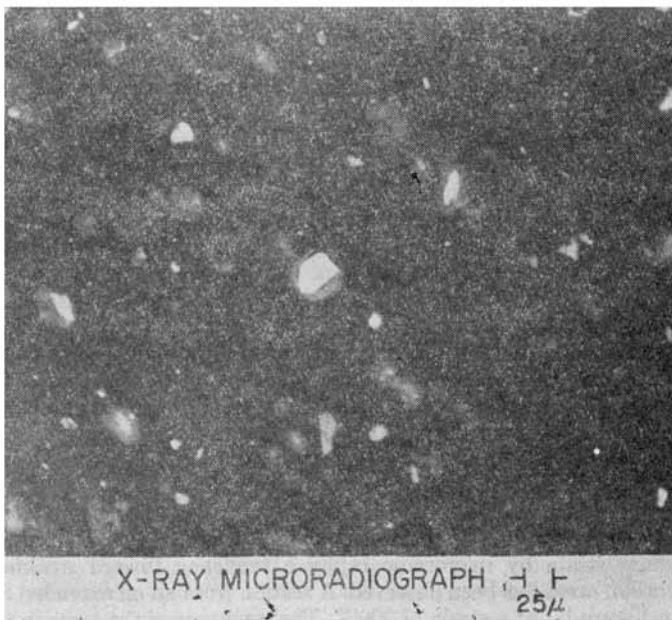


FIG. 8.—Reagglomeration areas showing high absorption nuclei.

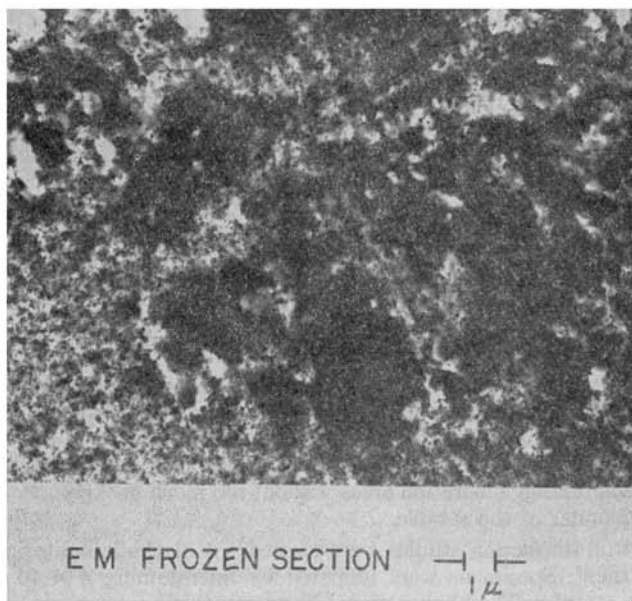


FIG. 9.—Reagglomeration area, OEP tread

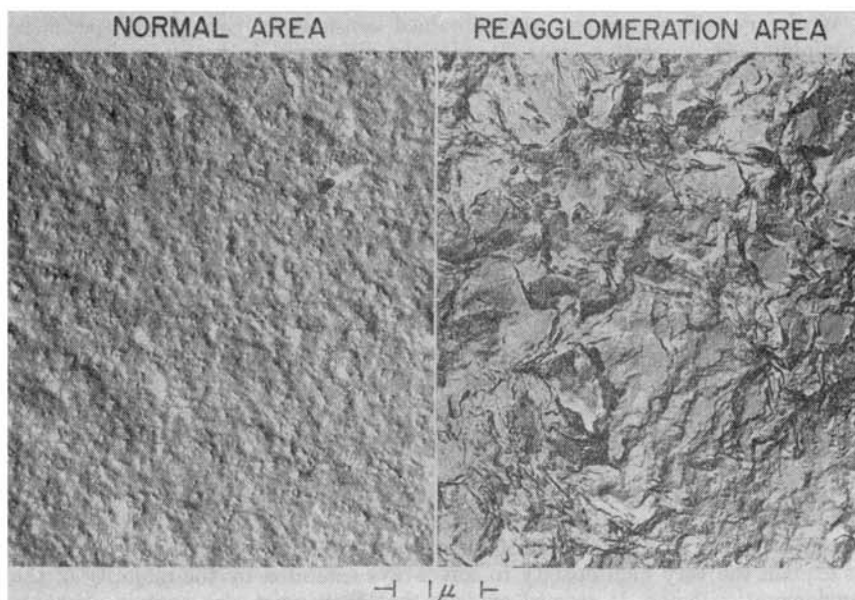


FIG. 10.—EM replicas—OEP tread.

open under strain appears to be related at least in part to their opacity to soft x-rays. The more dense areas appear to be the most brittle.

Figure 12 shows a section cut from the groove of a natural rubber truck tire which had been run for 19,000 miles. Severe reagglomeration was found throughout this tire. Repeated stretching of the section to 50% elongation produced the effect shown. Hairline cracks can be seen in most of the reagglomeration areas, again illustrating their relative weakness under stress. Longer stretching cycles on sections from this tread produced tears which tended to follow a path through many of the reagglomeration areas as shown in Figure 13. This is a particularly good illustration of the brittle nature of these regions. Some of them can be seen almost chunking out along the edges of the tear.

CHEMICAL COMPOSITION OF REAGGLOMERATION AREAS

Reflection electron diffraction was the first method employed in attempting to determine the chemical composition of the reagglomeration areas. This technique offered a distinct advantage over x-ray diffraction in that patterns could be obtained on very small areas down to about 50 microns in size. Thus it was possible to obtain patterns on single reagglomeration areas without too much background interference from the remainder of the sample.

The electron diffraction studies were carried out at the laboratories of Ernest F. Fullam, Inc.¹⁵ Specimens were prepared by microtoming 4×10 mm. blocks cut from tire samples. The final section (20 micron thickness) cut from each block was then examined by microradiography to check on the frequency of reagglomeration areas. The microscopical appearance of each final section was typical of the smooth surface remaining on the specimen block. The blocks themselves were employed as diffraction specimens. Samples of oil extended SBR and natural rubber treads, with and without reagglomeration, were examined.

Weak crystalline patterns were obtained consistently throughout specimens containing reagglomeration areas. Despite the differences in type of polymer and compound formulations these patterns were essentially the same in all the reagglomeration samples. The stocks showing no reagglomeration were almost completely devoid of any patterns at all.

The best identification of the crystalline areas in the reagglomeration stocks is that they represent wax. More specifically the patterns agreed quite well with that of ozocerite which is a mixture of aliphatic hydrocarbons similar to paraffin. A comparison of the interplanar (d) spacings of ozocerite and of the material in the reagglomerated stocks is shown in Table 1. Agreement is not perfect. However, lack of purity in the reagglomeration areas would be expected from the relative weakness of the patterns.

In support of the electron diffraction results, is a tendency toward birefringence in the reagglomeration areas observed when they are examined under polarized light. This effect is shown in Figure 14. Birefringence in the areas shown here was quite strong. However, many of the reagglomeration areas appeared quite weak in this respect.

Although the wax identification would tend to explain some of the characteristics of the reagglomerated material, such as its apparent ability to migrate throughout the rubber matrix, it was deficient in one respect. Areas of recrystallized wax could not explain the very high opacity to soft x-rays exhibited by the majority of the reagglomeration areas. It seemed evident that they must also contain elements fairly high up on the atomic scale.

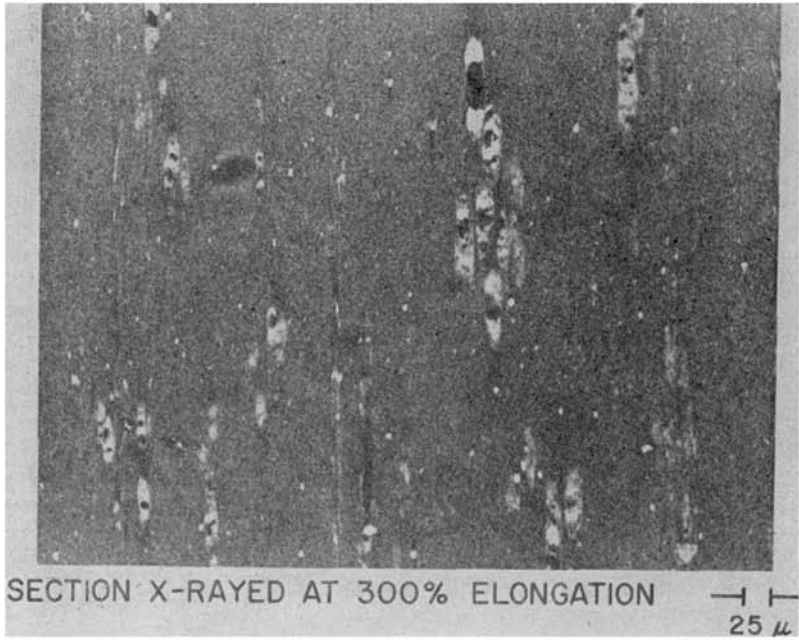


FIG. 11.—Reagglomeration areas under strain.

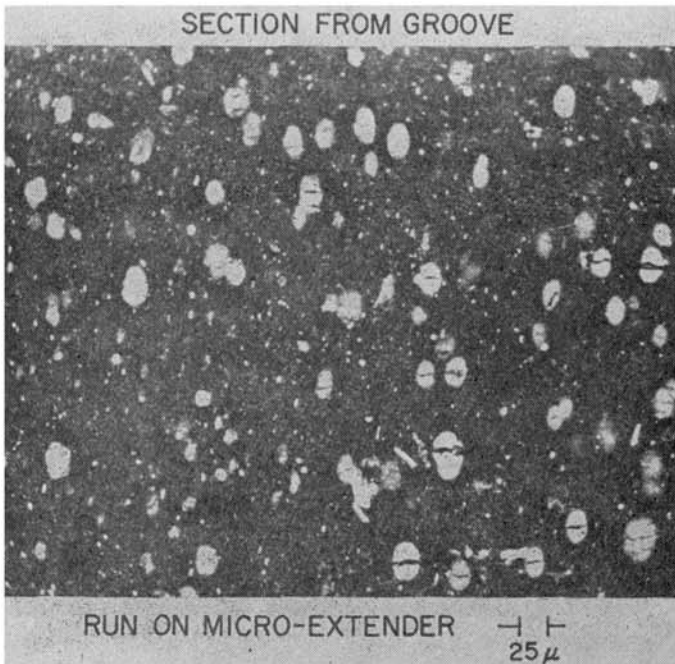


FIG. 12.—Badly cracked NR truck tire.

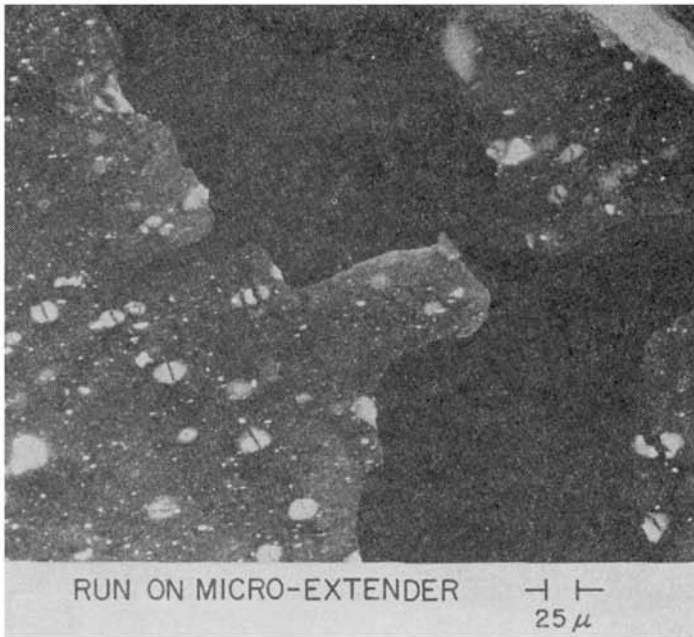


FIG. 13.—Badly cracked NR truck tire, showing tear in section from groove.

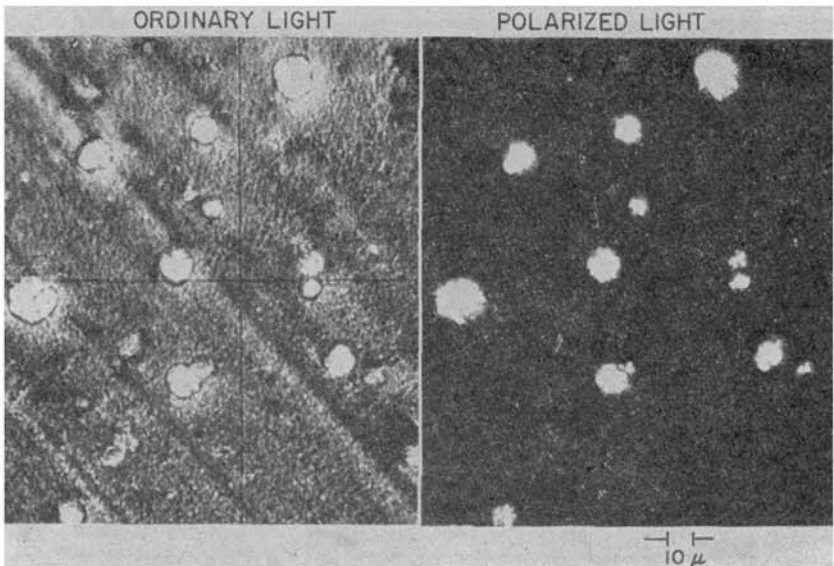


FIG. 14.—Reagglomeration areas showing birefringence.

TABLE 1
ELECTRON DIFFRACTION
d Spacings in Å

Reagglomeration Areas	Ozocerite
4.21	4.56
3.74	4.19
2.96	3.93
2.48	3.77
2.32	3.00
2.23	2.51
2.07	2.29
1.953	2.25
1.866	2.18
1.750	2.13
1.607	2.09
1.516	1.95
1.369	1.88
1.270	1.76
1.234	1.23

To learn what high mass elements were present within the reagglomeration areas the technique of electron beam microanalysis was employed. As in the electron diffraction studies it was possible with this method to obtain data from specific small areas. In this instance the beam could be focussed to a spot 1-2 microns in size.

These studies were carried out with an AMR electron beam microanalyzer at the laboratories of the Advanced Metals Research Corporation¹⁶. The specimen preparation technique was essentially the same as that employed for the electron diffraction studies. However, in this instance it was necessary to make the surface of the rubber specimens conductive to prevent excessive heat buildup under the very intense electron bombardment. This was accomplished by coating the top surface of the rubber blocks with a 4-500 Å layer of aluminum. It was then possible to carry out the examinations with only relatively slight heating effects.

Oil extended SBR and natural rubber treads, all containing an abundance of reagglomeration areas, were examined. Using a metallographic type microscope built into the equipment the reagglomeration areas could readily be resolved on the surface of the specimens. An analysis was made on several reagglomeration areas in each specimen as well as on the clear rubber matrix in the background.

TABLE 2
ELECTRON BEAM MICROANALYSIS
Composition of Reagglomeration Areas (weight %)

Element	Sample A		Sample B		Sample C	
	No.	Conc.	No.	Conc.	No.	Conc.
Sulfur	6	0.3	7	0.6	1	0.5
	9	0.6	2	0.8	6	0.7
	5	1.5	4	0.9	3	0.8
	2	2.0	3	1.1	6	1.0
Matrix		0.3		0.6		0.6
Zinc	2	0.7	5	0.6	4	0.6
	9	3.0	5	1.1	3	1.1
	1	3.5	4	2.3	5	1.8
	3	5.5	1	3.8	3	3.6
	Matrix		1.8		0.6	

The results of the electron beam microanalysis have shown conclusively that the reagglomeration areas tend to be rich in both zinc and sulfur. The results on three different specimens are summarized in Table 2. Sample "A" represents a natural rubber tread; samples "B" and "C" are oil extended SBR. Values are listed as weight %. They were calculated as a ratio of the intensity of the x-radiation emitted from the elements in the rubber samples over the intensity of the same elements in the form of pure standards. The matrix values refer to the levels of zinc and sulfur in the clear regions devoid of reagglomeration.

The zinc and sulfur levels were highest within the reagglomeration areas of sample "A", the natural rubber tread. This correlated with the microradiography results which showed the areas in this stock to be particularly high in x-ray absorption. Of interest also is the very low matrix sulfur level for sample "A" which tends to indicate that much of the sulfur in this stock has reagglomerated.

Another interesting phenomenon observed while these studies were being carried out was a tendency toward luminescence when the reagglomeration areas were struck by the electron beam. This would seem to indicate the presence of oxygen combined as an oxide (most likely ZnO) or possibly zinc sulfide which also fluoresces. Fluorescence was also exhibited by a multitude of smaller, more discrete clumps of material throughout the matrix of the samples. These were very rich in zinc only and were concluded to be zinc oxide.

RELATIONSHIP OF NON-CARBON REAGGLOMERATION AND CRACK DEVELOPMENT

Treads exhibiting a high degree of non-carbon reagglomeration have shown poorer resistance to crack development than those in which reagglomeration had not taken place or was present to a lesser degree. Examples of good and poor crack resistance in natural rubber treads are shown in Figure 15. The badly cracked tread is the same one listed as sample "A" in Table 2. Microradiographs of sections from the grooves of these two tires are illustrated in Figure 16. Both tires had been run for approximately 20,000 miles.

From the inherent weakness of the reagglomeration areas as demonstrated earlier in Figures 11, 12, and 13. It would be expected that they would aid in both the initiation of cracks and in their subsequent propagation under stress. Moreover, because they contain high amounts of sulfur and zinc one would also expect the reagglomeration areas to be regions of overcure. This fact alone would certainly decrease their resistance to cracking. As early as 1930 Booth¹⁷ demonstrated the poor crack resistance of overcured natural rubber stocks. The same tendency in SBR was shown by Breckley¹⁸ in 1943.

For the most part the reagglomeration areas associated with poor crack resistance have been resolved at fairly low magnification employing either microradiography or light microscopy. However, in some instances it has been necessary to resort to the higher resolution of the electron microscope via the replication method discussed earlier. A high concentration of very small reagglomeration areas in a tread groove are shown in Figure 17. This stock showed poor resistance to cracking but did not exhibit reagglomeration at the light microscope level.

VARIABLES INFLUENCING REAGGLOMERATION AND CRACKING

Several factors have been found to influence the tendency toward reagglomeration in tire treads. Of prime importance are the conditions under which the tread stocks are mixed. Factory stocks have shown a much greater tendency toward

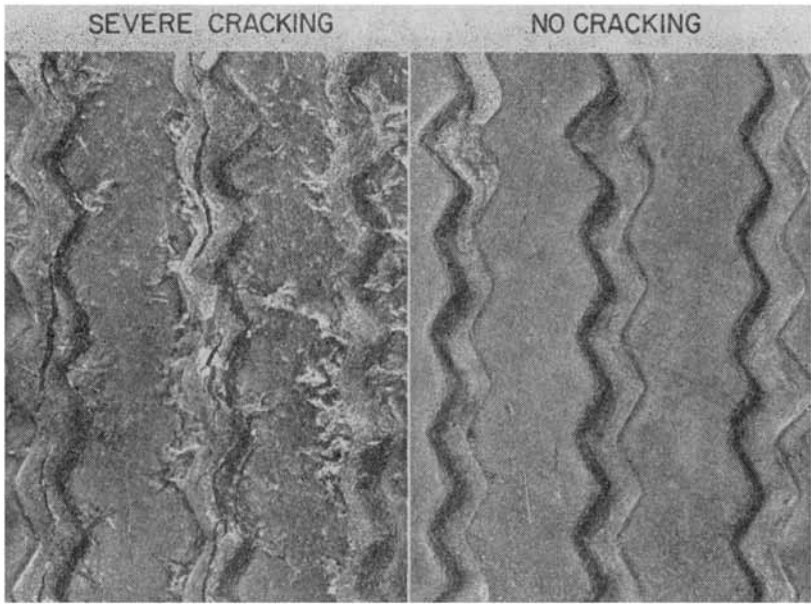


FIG. 15.—Comparison of worn threads

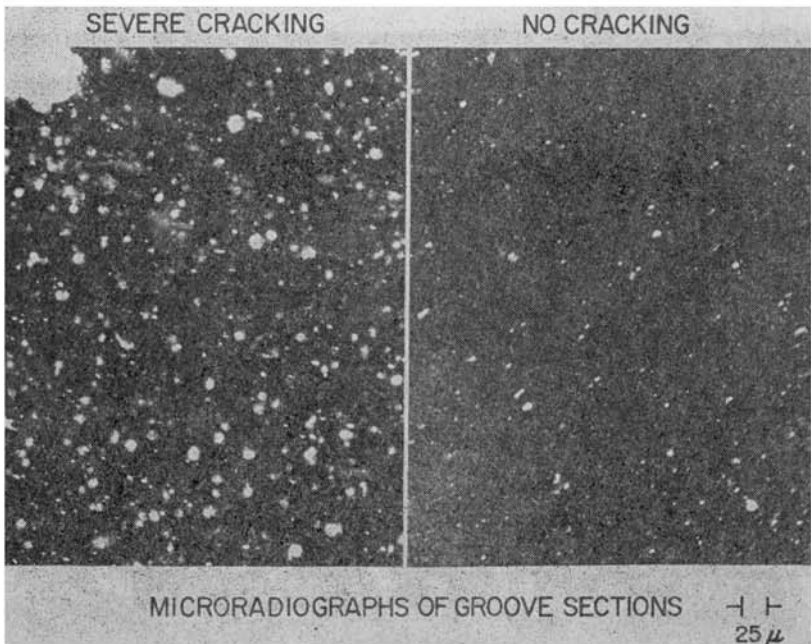


FIG. 16.—Comparison of worn threads.

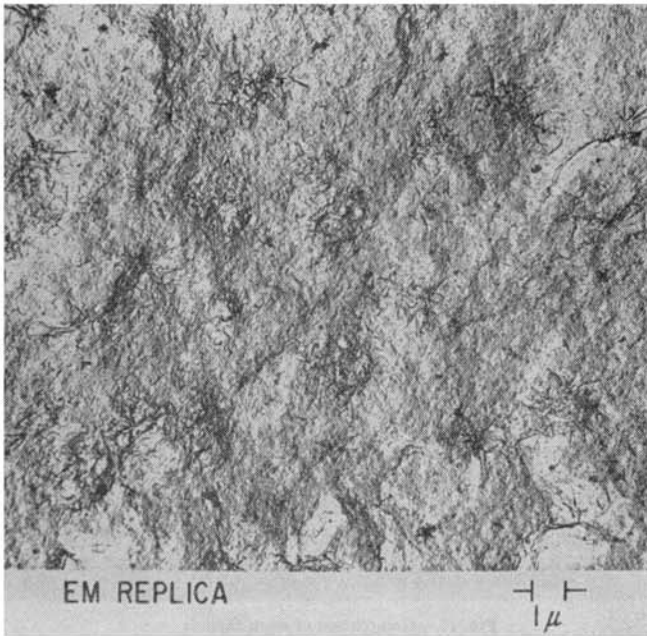


FIG. 17.—Smaller reagglomeration areas.

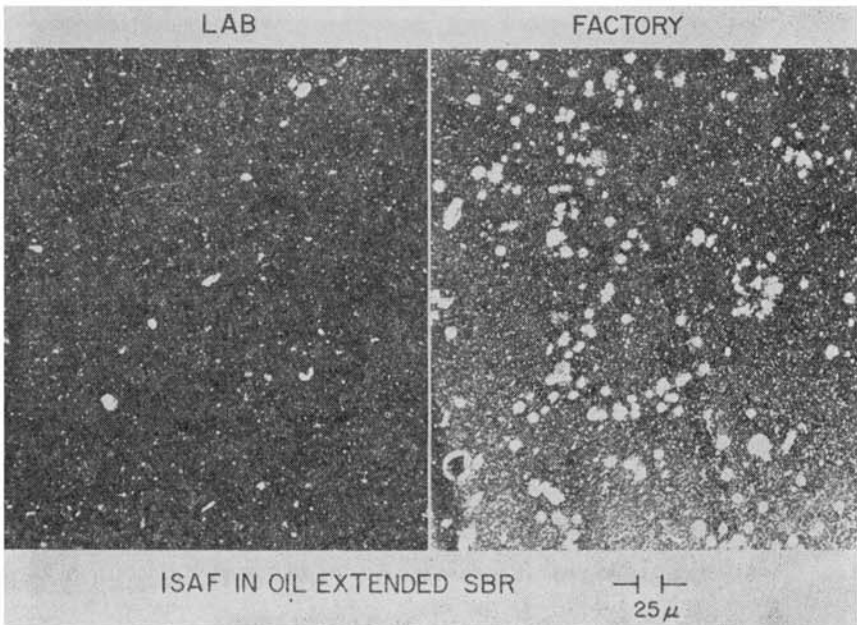


FIG. 18.—Effect of mixing conditions

reagglomeration than laboratory mixed stocks indicating the need for a good initial dispersion of all of the compounding ingredients. Excessively high mixing temperatures which are more apt to occur in the factory may also be a contributing factor. Typical examples of factory and laboratory mixed oil extended SBR treads are shown in Figure 18. Both tires had been road tested for about 10,000 miles. Severe cracking occurred in the grooves of the factory tread, no cracking at all in the lab mixed tire.

Certain compounding ingredients appear to influence the extent of reagglomeration particularly, as stated above, if they are not dispersed properly. The effect of excessive wax (5 PHR Paraffin) and zinc oxide addition in oil extended SBR treads are illustrated in Figure 19. In the case of the high zinc stock, double the normal amounts of zinc oxide and stearic acid were added to the compound. Both tires failed because of tread separations caused by large cracks in the grooves. Total mileages on the treads were comparatively low, in the range of 6000-7000 miles.

At this time it should be mentioned again that the phenomenon of reagglomeration has been found almost exclusively in tires that have been run on the road. Very extensive laboratory tests including DeMattia and Firestone Flex have been carried out with widely varying time and temperature conditions. These have all failed to produce reagglomeration. Only in one case did reagglomeration occur in a laboratory experiment. In this instance the conditions of high wax concentration and poor zinc distribution (as shown in Figure 3) were both present. The experiment was carried out using a standard laboratory ball mill. The rubber specimens were cut from a stress-strain slab into pieces 1/4 inch square. Steel balls 5/8 inch in diameter were employed. The ratio of the weight of the balls to the sample weight was about 150-1. Reagglomeration was first observed after about 100 hours of ball milling. Figure 20 shows a microradiograph of one of the ball milled specimens at 168 hr. Also shown is an area on the control stock illustrating the uneven zinc oxide distribution prevalent in this stock. These streaky areas were not dissipated by ball milling as they had been on the dynamometer as mentioned earlier. A similar compound with a uniform dispersion showed no reagglomeration via the ball mill test even after 300 hr.

During ball milling the rubber specimens appear to be getting both the abrasion and severe pounding which a tread receives during operation at high speeds. This is a test which certainly merits further investigation.

The type of carbon black also appears to play a part in the tendency for the other ingredients to reagglomerate during tire operation. The effect of carbon particle size in oil extended SBR is shown in Figure 21. Both of the laboratory mixed stocks shown here were run for a total of about 18,000 miles. The ISAF sample cracked; the HAF did not. These results appear to be in line with the lower running temperature of the coarser HAF type black.

ISAF tread carbons exhibiting a low degree of chain structure have given poorer crack resistance in oil extended SBR than blacks of the same fineness which are at a normal or high structure level. This tendency is attributed to the greater tread movement caused by the low structure type black. An extensive program was carried out employing factory mixed tires to study the effect of black structure on reagglomeration. The blacks compared were LS-ISAF, regular ISAF and high structure ISAF. Master batches of each black were prepared by means of the Columbian Black Rubber Process to eliminate any differences in carbon black dispersion.

Reagglomeration and cracking were most severe for the LS-ISAF and least severe for the high structure black. Sections cut vertically from the grooves of tires

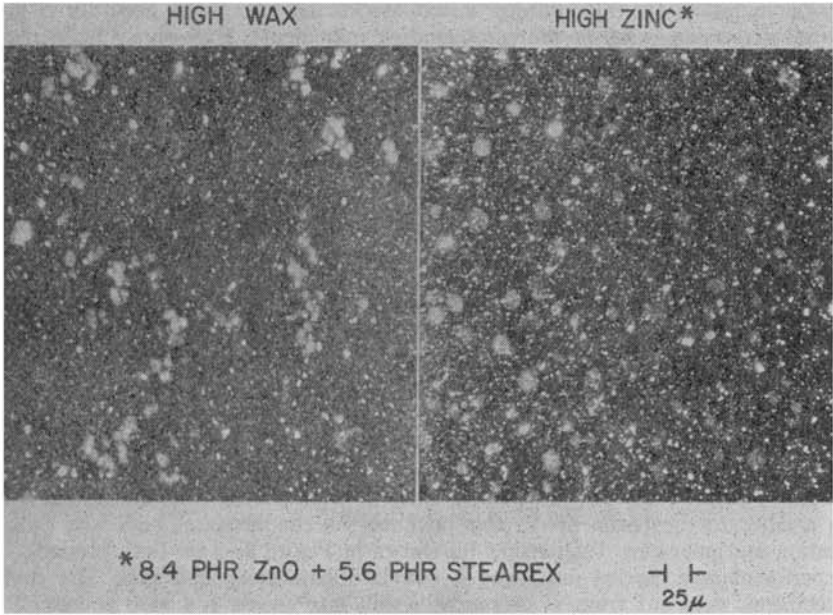


FIG. 19.—Effect of compounding variables.

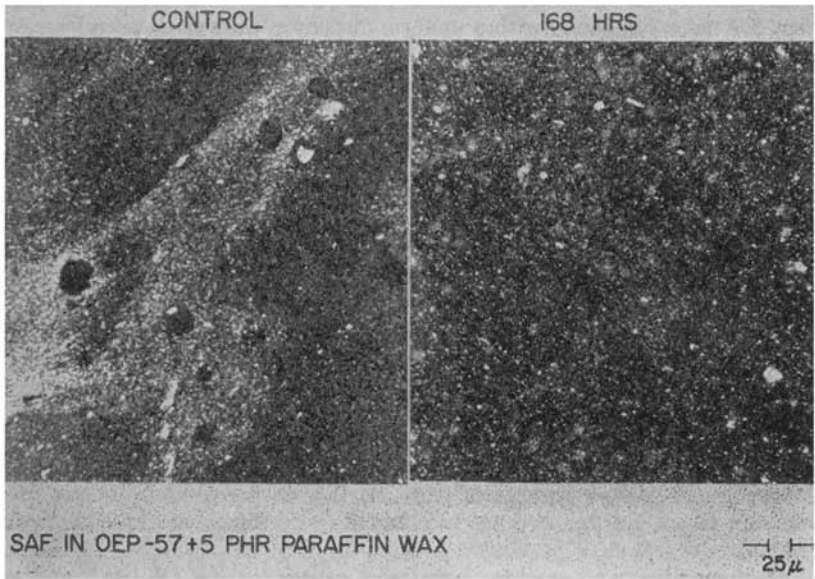


FIG. 20.—Effect of ball milling.

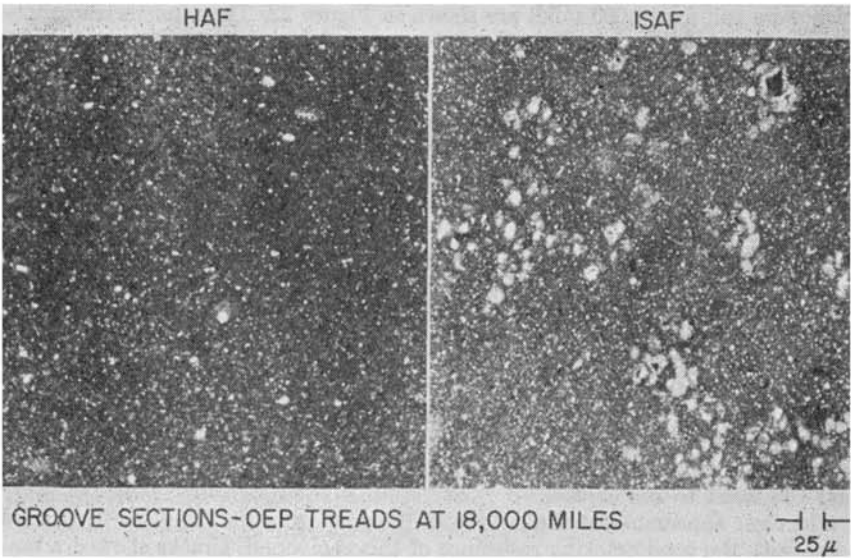


FIG. 21.—Effect of carbon fineness.

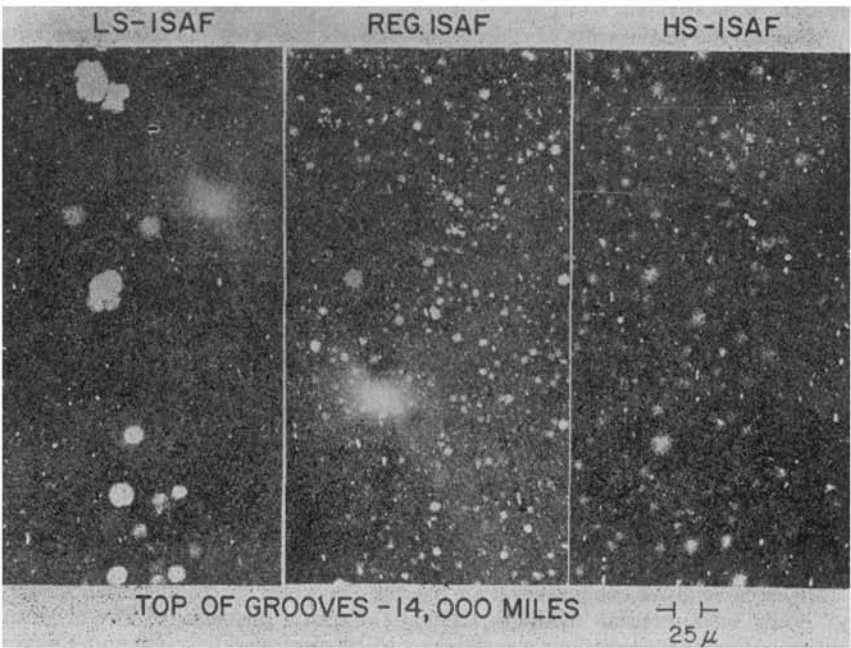


FIG. 22.—Comparison of ISAF carbons in OEP.

which were run for 14,000 miles are shown in Figure 22. These microradiographs show the top of the grooves. Very large, dense reagglomeration areas were observed at the top of the grooves in most of the LS-ISAF treads. Areas of this type, although fewer in number than those in the other two stocks, would be expected to be more damaging, particularly with respect to crack initiation. Another microradiograph of this same LS-ISAF tire is shown in Figure 23. Here the section was cut laterally near the top of a groove and shows a profile of the edges of an actual crack. Unfortunately, due to dirt picked up during tire operation detail along the crack edges is not too good.

Figures 24 and 25 show at lower depths the same grooves which were illustrated in Figure 22. In these lower regions the reagglomeration areas were also more dense in appearance for the LS-ISAF. Significantly fewer areas were apparent at lower groove depths for the HS-ISAF. This is particularly noticeable in Figure 25 in which the tread-undertread interfaces are shown. At the bottom of the grooves the high structure black showed a tendency to be devoid of reagglomeration while the other two carbons showed areas down to and into the undertread. Of interest is the fact that there was always a fine strip above the undertread in which no reagglomeration occurred. This clear area may represent the cement used to bond the tread to the carcass.

The clear appearance at the bottom of the grooves in the HS-ISAF tires were in line with the good cracking resistance of this compound. Cracks showed a tendency to be deeper when reagglomeration occurred throughout the whole groove from top to bottom. Shown in Figure 26 is a groove section cut from an LS-ISAF tire which failed as a result of a bad crack and subsequent tread separation. The area shown in this microradiograph was at the base of the groove near the separation. Note the linear alignment of reagglomeration areas just above the undertread. The clear zone between tread and undertread is again also apparent.

Although the final results of this program clearly indicated the poorest cracking resistance for the LS-ISAF carbon, one of the treads of this black failed to crack at all. Since all the tires were run under essentially the same conditions no explanation can be given for this result. However, the appearance of the grooves in this tire coincided with the cracking results in that they were devoid of reagglomeration as shown in Figure 27.

The blending of oil extended SBR with polybutadiene appears to reduce the cracking tendency associated with the use of ISAF tread carbons. Microscopical examination of 50-50 oil extended SBR/BR treads has indicated little or no reagglomeration. This is attributed to the better wetting characteristics of the polybutadiene polymer and possibly also to somewhat lower heat buildup. A section from the groove of a 50-50 OEP/BR tire run for 8700 miles is shown in Figure 28. There was no reagglomeration or cracking in this tire. The specimen was x-rayed at 300% elongation to illustrate the excellent wetting of all compounding ingredients.

SUMMARY

Tread groove cracking of oil extended SBR and natural rubber tires has been associated with a reagglomeration of zinc and sulfur during service. In SBR treads this phenomenon is favored by the presence of small particle size, low structure blacks and paraffin or similar waxes.

The occurrence of reagglomeration has been established by microradiography and other microscopical methods including electron microscopy. The chemical identity of these configurations was determined by electron diffraction and electron beam microanalysis.

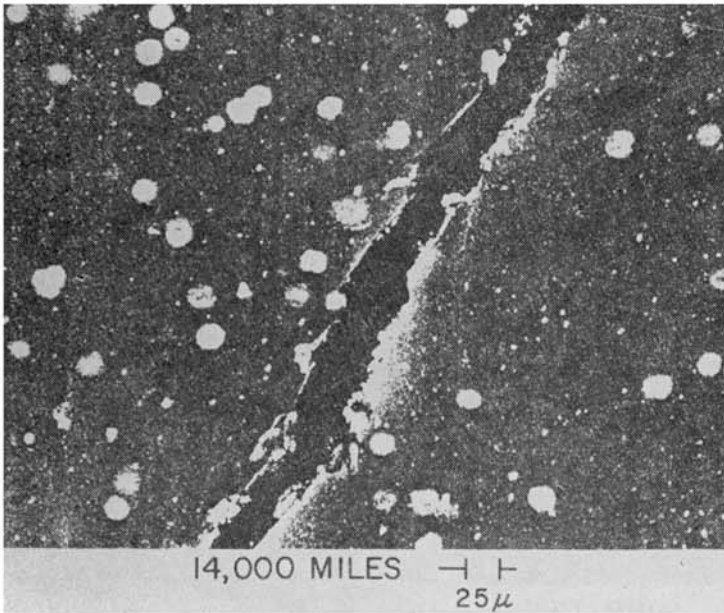


FIG. 23.—Actual crack in groove.

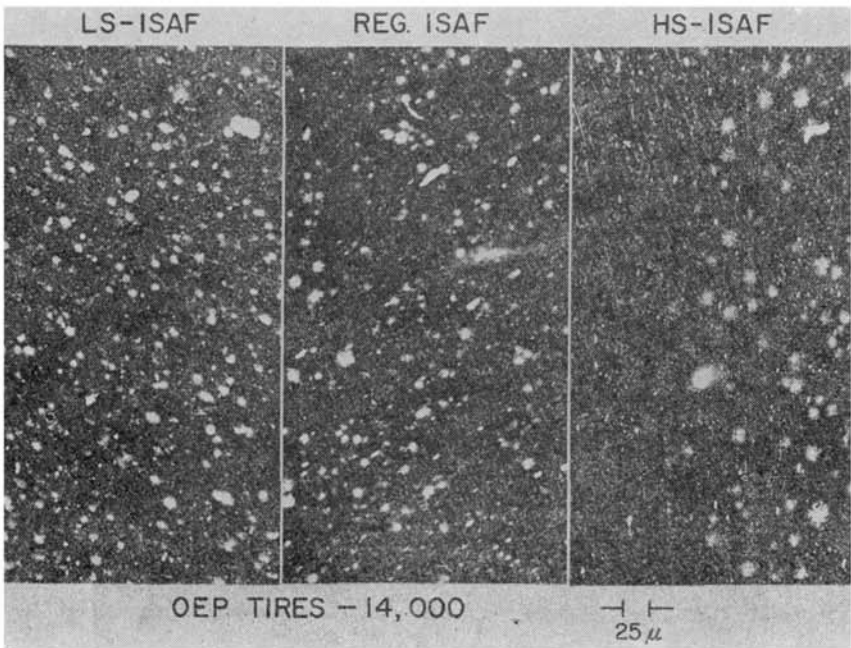


FIG. 24.—Middle depth of tread grooves.

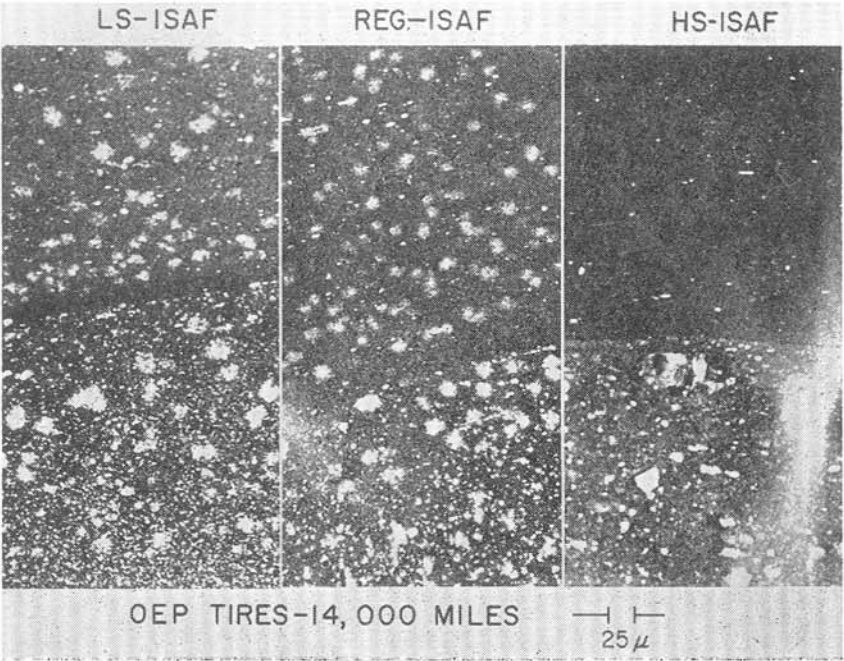


Fig. 25.—Bottom of tread grooves.

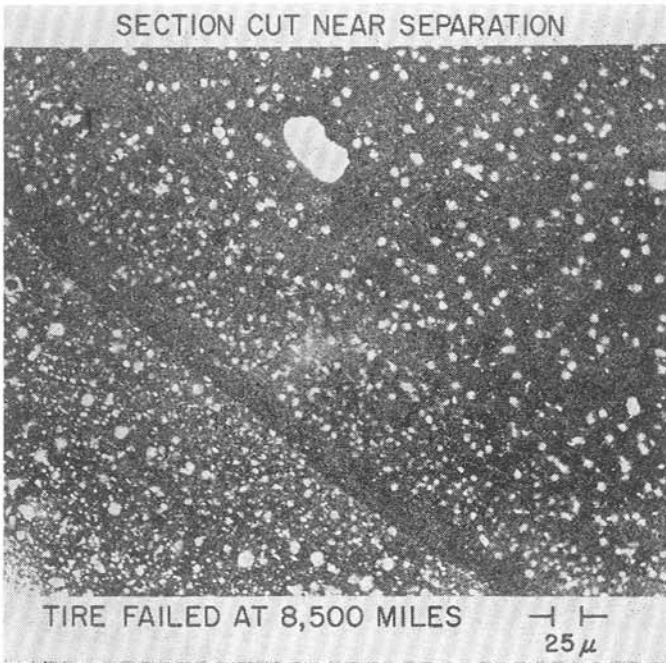


Fig. 26.—LS-ISA in OEP—groove bottom.

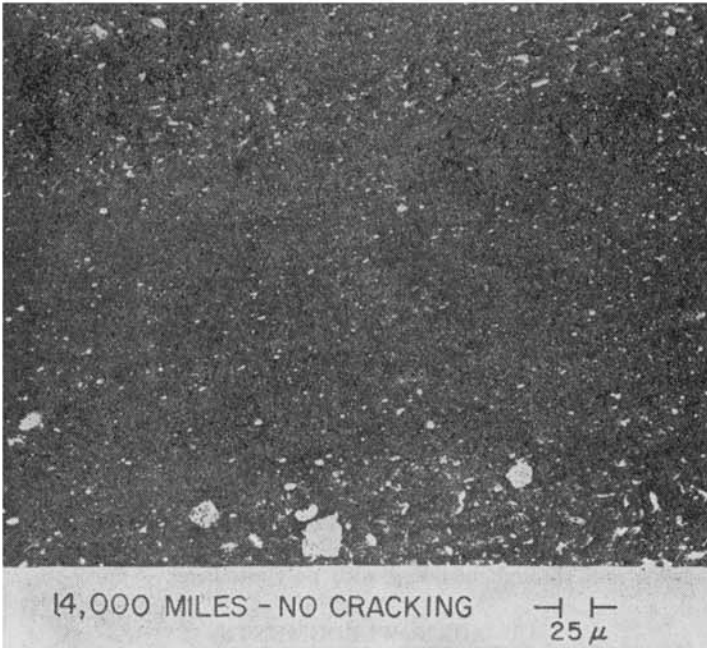


FIG. 27.—LS-ISAF in OEP—groove.

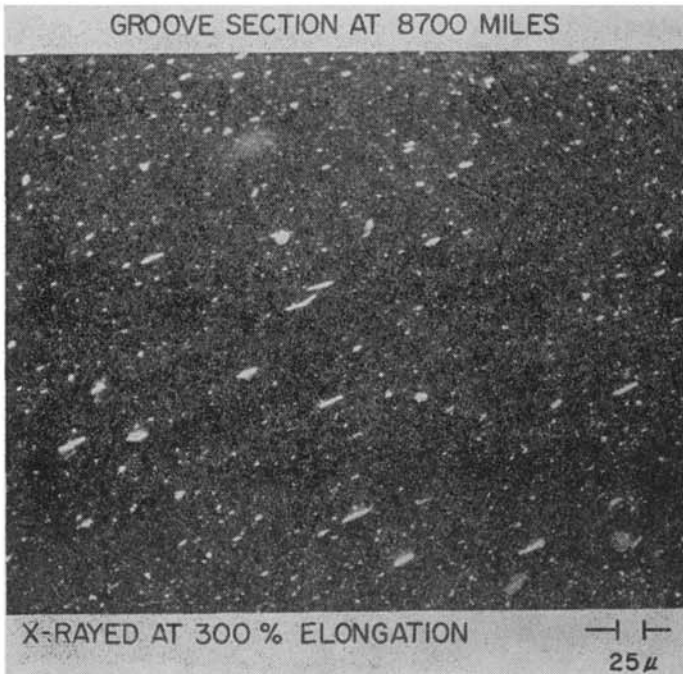


FIG. 28.—ISAF in OEP-BR blend.

Areas of reagglomeration appear to contribute to both the initiation and propagation of cracks as shown by microscopical observation of actual tread sections under stress.

Reagglomeration in oil extended SBR may be minimized by the use of larger particle size or higher structure carbon blacks and through improved dispersion of non-carbon ingredients.

CONCLUSIONS

A tendency for zinc and sulfur to reagglomerate, along with wax, has been observed in oil extended SBR and natural rubber tires. In high concentrations these relatively brittle reagglomeration areas are associated with poor resistance to groove cracking.

The pigment-polymer environment has a significant effect on the occurrence of non-carbon reagglomeration. An increase in reagglomeration in oil extended SBR treads is favored by:

1. Poor initial dispersion of the non-carbon components.
2. Fine particle size and low structure carbon blacks.
3. Excessive zinc and wax.

Conversely, reagglomeration can be reduced or eliminated by good dispersion of all compound ingredients, the use of higher structure or larger particle size carbon blacks, and through blending with polybutadiene.

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