CHAPTER-8:

CONCLUSION

8.1 Introduction

Tyre is the crucial part of vehicles which carries the load, offers steering response and provides grip to the vehicles. However, tyres cause increased fuel consumption due to its rolling resistance and increases the generation and emission of greenhouse gases. Hence reduction of tyre rolling resistance is a necessary aspect of tyre development. It has been demonstrated that a reduction of tyre rolling resistance by 30% would lead to around 3 to 6% lower fuel consumption by the vehicles.

The major contribution of tyre rolling resistance is caused by the tread. Tread is the major and most crucial part of tyre, which remains in contact with road during service, hence abrasion resistance, wet traction property, stiffness and mechanical strength are also the key properties of tyre tread compounds.

Carbon black, used as filler in rubber compound provides mechanical strength, stiffness, abrasion resistance to the tyres. Incorporation of carbon black in the rubber compound also results in filler-filler interaction and hysteresis energy losses which enhances heat buildup and rolling resistance of tyre tread compounds.

In this research work, different grades of carbon black were developed using the furnace process to investigate the carbon black characteristics for best fit tyre tread compounds based on different area of applications. The research also includes post treatment of commercially available ASTM grades by ozone treatment and surface modification by BTEAC treatment in order to enhance filler dispersion and thereby reduce rolling resistance, heat buildup as well as improving durability of tyre tread compounds.

8.2 : Modification of Tyre Tread Compound by Optimized Aggregate Size and Aggregate Size Distribution of Carbon Black

In this part of the study carbon black was developed based on broad aggregate size distribution where the broadness aggregate size distribution was represented by FWHM value and high value of the same indicates broad aggregate size distribution for the carbon black. It concludes carbon black characterized with broad aggregate size distribution results in increased interaggregate distance that leads to lower Payne effect in rubber matrix. Broad aggregate size distribution of carbon black provides low hysteresis loss in rubber compounds, which provides low rolling resistance in tyre tread compounds.

It is seen that carbon black with narrow aggregate size distribution provides enhanced wear resistance property when surface area and structure of the same remain intact however, to achieve the enhanced abrasion resistance property of tyre tread compound, a carbon black with narrow aggregate size distribution, high structure and high surface are well recommended.

In another aspect of the study, the effect of bigger size aggregates has been analyzed on rubber performance. The carbon black possessing larger extent of bigger size aggregates provides low Payne effect and low hysteresis property in tyre tread compound. The extent of bigger size aggregates present in carbon black was represented by differential volume distribution (dV/dD) values for the specific aggregate size at the region of larger aggregate sizes. Differential volume distribution value at 150 nm aggregate size was denoted by $(dV/dD)_{150}$, a carbon black having larger value of $(dV/dD)_{150}$ indicates it has larger extent of bigger size aggregate of 150 nm. It is seen carbon black with larger value of $(dV/dD)_{150}$ provides reduced Payne effect, low heat buildup property and low rolling resistance property for the tyre tread compounds. Hence to design low hysteresis and low rolling resistance tyre tread compound, a carbon black with broad aggregate size distribution, or a carbon black characterized with larger extent of bigger size aggregates are considered as the key to carbon black development.

8.3 Correlation of Carbon Black Parameters with Rubber Compound Properties for Development of Improved Tyre Tread Compounds

Apart from the full width half maximum (FWHM) value and the aggregate size distribution, carbon black is characterized with different distribution parameters, such as mean aggregate size ($\bar{X}$), mode of the aggregate size distribution, 'd_n' values etc. The mean aggregate size is the arithmetic average size of different aggregates presents in carbon black while mode value is described as the maximum occurrence of aggregate size. The 'd_n' is defined as the limit of the aggregate size, which occupies 'n%' of total aggregate volume in the carbon black.

In this study it is demonstrated that carbon black with smaller aggregate size has a significant impact on Payne effect and heat buildup property of rubber compound. The d_{10} value is a potential parameter of carbon black, which represents smaller size aggregates present in the carbon black. The lower d_{10} value of carbon black indicates presence of large extent of smaller size aggregate present in the carbon black. Carbon black possessing lower aggregate size has strong affinity to form filler-filler network and leads to high Payne effect and high heat buildup in rubber compound.

To establish a correlation between aggregate size distribution characteristics of carbon black an 'aggregate size distribution co-efficient (A) parameter, has been introduced which is function of FWHM and mean aggregate size. It has been found that aggregate size distribution co-efficient (A) parameter has linear relationship with tanδ value measured at 60ºC with a positive slope of the plots and significant R-square value. This demonstrates increase of mean aggregate size or FWHM value or both parameters of carbon black favor in achieving low hysteresis property of rubber compounds and benefits for lower rolling resistance of tyre tread compounds. It is also demonstrated that FWHM is predominant parameter over mean aggregate size for controlling hysteresis energy loss of rubber compounding.

The abrasion resistance property of the rubber compound is predominantly controlled by the structure property of carbon black while the surface area of the same remains in the similar range. In this investigation a unique 'structure co-efficient parameter ($\hat{S}$) has been introduced, which covers effect of both structural units such as primary structure associated with aggregate as well as secondary structure associated with agglomerates. It demonstrates that carbon black with high 'structure co-efficient parameter' value results in enhanced abrasion resistance property of rubber compounds. It has been also observed that aggregate size plays a role in abrasion resistance property of rubber compound and carbon black with lower mean aggregate size and lower mode value provide superior abrasion resistance property for the tyre tread compounds.

8.4 Simultaneous Changes on Carbon Black Surface and Structural Morphology to Improve Tyre Tread Compounds

In this part of the study commercially available carbon black of ASTM grade N330 was post treated with ozone which affects the surface morphology of carbon black as well as on surface chemistry of carbon black. Carbon black surface morphology is associated with its unique morphological composition, which consists of different layers of graphitic units. The arrays of graphitic layers cause crystallinity on its surface and extent of the arrangement determines extent of the surface crystallinity. On treatment of carbon black with the ozone, the arrays of graphitic layers get distorted, which disintegrate crystallinity of carbon black and results in an increase in amorphous behavior of carbon black. The level of conversion from crystallinity to amorphous behavior depends on intensity of carbon black oxidation by ozone treatment. Oxidation by ozone treatment causes generation of porosities on carbon black surface which increases the nitrogen surface area of carbon black.

N330 grade is further associated with substantial functionalities on its surface which are generated during the manufacturing in the furnace process. On treatment of carbon black with ozone, the characteristics of these functional groups could alter their characteristics due to the oxidation. Moreover, oxidation causes increased amorphous nature of carbon black, and amorphous parts of the carbon black are known to assist in surface functional groups attachment on the carbon black surface, as a result, an increased surface functional groups are generated on the carbon black due to the ozone treatment.

The surface functional groups are primarily oxygen containing and acidic in nature, which turns carbon black to acidic behavior and reduces its pH value by treatment with ozone. The high surface functional groups generated on carbon black surface increases its volatile matter content when the same is heated in an inert atmosphere under a controlled thermal treatment.

The effect of oxidized carbon black was studied in different rubber systems based on tyre tread compounds. In this investigation different extent of oxidized carbon black were used which were oxidized for 15 minutes, 30 minutes and 60 minutes. Ozone treated carbon black provides low rolling resistance property in different tyre tread compounds based on SBR1712-BR as well as SSBR-BR rubber system. Ozone treated carbon black enhanced surface functional groups compared to the non-treated ASTM grade carbon black hence it is observed ozone treated carbon black provides increased efficiency toward polar rubber system based on SSBR-BR in which SSBR is characterized with polar living functional groups. Hence SSBR-BR system provides superior performance in rolling resistance reduction compared to SBR1712-BR rubber system when ozone treated carbon black is used.

Ozone treated carbon black further increases storage modulus and enhances abrasion resistance for SSBR-BR based tyre tread compound, hence, a combination of SSBR rubber system with ozone treated carbon black could be considered as preferred materials for the new generation tyre technology for electric vehicle (EV) applications, where rolling resistance, mechanical strength, abrasion resistance and tyre stiffness are recommended.

8.5 Improvement of Tyre Tread Compounds by Treatment of Carbon Black with Benzyl Tri-Ethyl Ammonium Chloride (BTEAC)

Commercially available carbon black has functional groups on its surface which can be utilized to react with different chemicals in order to modify the chemical nature of the surface of carbon black. In this investigation N330 carbon black was chemically modified with BTEAC to modify its surface chemistry. It is seen on treatment of N330 grade with BTEAC, the pH of carbon black is increased. Hence it is plausible by BTEAC treatment, amino derivatives are attached on carbon black surface.

Thermogravimetric analysis indicates a substantial weight loss of the BTEAC treated carbon black which confirms a large quantity functionalized groups are attached to carbon black surface. Simultaneously on BTEAC treatment there is a reduction of iodine adsorption number of carbon black which indicates presence of bulky groups attached on carbon black surface, hence functionalization of carbon black with BTEAC could cause attachment of benzyl and ethyl groups on the carbon black surface. Functionalization of carbon black with BTEAC treatment does not alter the basic morphological characteristics of carbon black such as particle size, aggregate size, aggregate shape, and aggregate size distribution etc.

Effect of BTEAC treated carbon black was studied in different rubber compounds. On treatment of carbon black with BTEAC the surface chemical nature of carbon black was modified. The attachment of ethyl, benzyl and amino derivative on modified carbon black makes carbon black more compatible with rubber molecules, as a result, the filler-polymer interaction was increased and consequently the propensity of filler re-agglomeration as well as filler network formation was reduced. Lower filler-filler interaction and the improvement of filler-polymer interaction of treated carbon black with respect to the control compound help in reducing Payne effect of the compounds up to 25%.

It is noted that dispersion and distribution of carbon black in the rubber matrix were significantly improved by treatment of carbon black with BTEAC and due to the enhanced dispersion of BTEAC treated carbon black the abrasion resistance of rubber compound is improved. BTEAC treated carbon black further reduces hysteresis energy loss significantly and results in low rolling resistance for tyre tread compound.

BTEAC treatment of carbon black can benefit in increase of filler loading without any detrimental effect. It is observed that due to increase of filler loading by 5 phr, the abrasion resistance, stiffness and wet traction property of rubber compounds increase. Thus, incorporation of 5 phr higher BTEAC treated carbon black can be considered as preferred selection for electric vehicle tyre tread compound where reduced rolling resistance, enhanced abrasion resistance and high compound stiffness are essential.

8.6 Future Scope

The objectives of the present studies was to improve tyre tread compound by modification of carbon black. In this research work by different method of carbon black modification, tyre tread compound performances were enhanced by reduction of rolling resistance up to around 20%, enhancement of storage modulus by 25%, enhancement of mechanical strength, reduction of heat buildup property and enhancement of abrasion resistance beyond 10%. However, there is still plenty of scope available which can be addressed in the future.

- Modification of carbon black aggregate size distribution, characterized with specific size of aggregates for the specific rubber properties. In which carbon black aggregates which causes detrimental effect for specific property of rubber compound, that can be removed or minimized from the carbon black.

- A carbon black combined of optimized FWHM value and optimized extent of large aggregate size or optimized extent of small aggregate size or other aggregate size distribution parameter can be identified for specific tyre tread compound.

- In the current investigation different modification of carbon black is studied in only SBR-BR or SSBR-BR and NR based rubber systems, however, different rubber manufacturers have developed a good number of functionalized rubbers based on solution styrene butadiene rubber, polybutadiene rubber, natural rubber etc. Modified carbon blacks could be developed for this rubber system to improve their performance in tyre tread compounds and this can be the potential scopes for future study.

- To develop carbon black for specific performance enhancement of tyre tread compound the correlations of rubber properties were conducted with few of the aggregate size distribution parameters and the carbon black structures. Carbon black has different features which can be further correlated with different rubber compound properties for the tyre tread applications in order to find out innovative scopes for development of new generation carbon black.

- Carbon black was treated with ozone which has changed the morphological feature and surface chemistry of carbon black. A further study could be carried out to functionalize ozone treated carbon black with BTEAC or other chemical to study in different tyre tread compounds.

- The treatment of carbon black with different rays and radiation can be considered as suitable future scope of investigations for modification of carbon black morphology and finally to investigate its effect on tyre tread compounds.