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Experimental investigation on effects of elastomer components on dynamic and mechanical properties in seismic isolator compounds

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HIGHLIGHTS

- Development of steel reinforced elastomeric isolator (SREI) compounds.
- Comparison between DMTA and ISO shear test results of elastomeric compounds.
- Introducing an experimental approach to improvement of SREI compounds.
- Research in the interstitial field between structural engineering and polymer science.
- Investigation of the effect of dynamic strain on shear modulus and damping ratio of SREI compounds.

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ABSTRACT

Elastomeric bearings are becoming a preferred device for isolating bridges, buildings, and sensitive equipment structures. The technical specifications used to procure these isolators are considered as important factors for the consumers. Lack of communication between structural engineers and rubber technologists, causes structural engineers have slight understanding of rubber properties. In the present study, a number of compounds were initially designed and manufactured, based on a previously studied and manufactured isolator compound. The outcome of the experiments indicated the physical and mechanical properties. Afterwards, the targeted improvement led to modification of the compounds formula. Finally, the dynamic shear properties of compounds were obtained from ISO standard tests and the comparison between results, revealed the effect of compound components.

1. Introduction

Rubber is one of the most important products which is currently used for various engineering purposes. The growing use of rubber in engineering applications, results from its particular properties, such as high extensibility, high energy absorption, and tolerable environmental resistance [1]. Materials such as steel, fabric, cords and fiber are often combined with rubber to form composites. Elastomeric bearings, as one of these composite products, are widely used throughout the world for seismically isolating buildings, bridges and sensitive equipment structures. Seismic isolation system and specially the steel reinforced elastomeric isolators (SREIs), as the most widely used type of this system, is continuously developing in the recent years as confirmed by the increasing number of applications throughout the world. It shows the possibility of protecting the structural and non-structural elements of buildings from failure, because this system provides the flexibility and decouples the superstructures from ground motion.

Elastomeric bearings are usually designed or selected by structural engineers, who may have a firm perception of structural requirements, but have slight understanding of the properties of the elastomers, especially in terms of different behavior compared to concrete and steel, when used to transfer loads. Conversely, rubber technologists and polymer scientists understand the chemical compounds and the behavior of elastomers, but they have limited knowledge about structural requirements [2,3]. Some research studies have been conducted on improving the properties of elastomeric bearings with a focus on compound structures. Warn and Ryan [4], Derham et al. [5], Naeim and Kelly [6] investigated the influence of the carbon black amount on rubber properties. They suggested that a higher level of damping was achieved through addition of carbon black to the raw rubber during the mixing process. Martelli [7] worked on improving bearing

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Nomenclature

Acc.	accelerator	phr	part per hundred rubber
CB	carbon black	Q1	maximum shear force
DMA	dynamic mechanical analysis	Q2	minimum shear force
E_D	energy dissipated by damping	SBR	styrene butadiene rubber
E_S	strain energy	SREI	steel reinforced elastomeric isolator
EV	efficient vulcanizing	t_r	thickness of one rubber layer
Frq.	frequency	t_s	thickness of one reinforcing steel plate
G'	elastic shear modulus (storage shear modulus)	X1	maximum extension
G''	loss shear modulus	X2	minimum extension
G^*	complex shear modulus	ΔW	area enclosed by the hysteresis loop
G_{eff}	effective shear modulus	γ	shear strain
h_{eq}	equivalent damping ratio	γ_{max}	maximum shear strain
NR	natural rubber	δ	phase angle (loss angle)
PA	protective agent	η	loss factor
PBR	polybutadiene rubber		

characteristics using modified compounds. In situ snap back testing and shake table testing has provided valuable data. Kelly [8] reported the results of a large program of bearing testing which was designed and was procured from several bearing manufacturers in the United States, United Kingdom, Japan and Italy. These were tested at EERC to determine their mechanical behavior and to study their failure mechanisms. Payne [9,10] studied effect of carbon black structures, degree of vulcanization and degree of dispersion on dynamic properties of rubber. Muhr [11] investigated the effect of dynamic strain and carbon black loading on shear modulus and damping of rubber compounds for engineering applications and presented rough relationship between rubber hardness and shear modulus. Chuayjuljit et al. [12] conducted an experimental study on the effect of particle size and amount of filler on dynamic mechanical properties of vulcanized natural rubber. Nah et al. [13] investigated the influences of carbon black loading and cure type on the dynamic mechanical properties of styrene butadiene rubber compound. Bettinali et al. [14] studied for the optimization of the design and the performance of high damping rubber bearings for seismic isolation. Kulak and Hughes [15] carried out number of experimental tests on three different elastomers manufactured by three great companies. They find nominal mechanical response properties and variations with strain level, loading rate, and cycles. Sun [16] focused on experimental study on the elastomer material from the steel reinforced elastomeric bridge bearings. A new shear test methodology was introduced and different hyper-elastic material models were calibrated based on these tests. The most research studies in the field of material study of the bearings, usually investigate how one component of elastomer compounds influences its properties. However, no research was found that included the investigation the effects of some compound components on dynamic and mechanical properties, especially for SREIs. On the other hand, there are several standards which give criteria for material properties for structural and bridge bearings. EN 15129 [17] specifies material characteristics of anti-seismic devices including elastomeric isolators; EN 1337-3 [18] applies to elastomeric bearings and specifies the range of physical and mechanical properties of elastomeric materials; ISO 6446 [19] specifies requirements for rubber materials used in elastomeric bridge bearings and ASTM 4014 [20] determines standard specification of elastomeric materials for bridge bearings. These standards don't mention anything about effects of components of elastomeric compounds on properties of rubber materials. Therefore, it seems that more research is required in this field to investigate the effect of elastomer components on dynamic and mechanical characteristics of seismic isolator compounds.

Dynamic and mechanical properties of rubber play a very important role in the design of SREIs. In this research, an experimental investigation on effects of elastomer compound ingredients on dynamic and mechanical properties of products is presented.

A generic compound contains elastomer(s), fillers, plasticizers, protective agents and vulcanization additions and some other important ingredients. On the other hand, it is important to improve the dynamic and mechanical properties of seismic isolator compounds such as tensile strength, damping, elongation at break, compression set, ozone resistance, aging, adhesion to steel and processability.

Compounding can be divided into following main systems:

- Rubber system, can include one or more rubbers
- Filler system, contains reinforcing filler and non-reinforcing filler
- Plasticizers
- Protectants, contains antioxidants, antiozonants and inhibitors
- Process aids
- Cure system, contains vulcanizing agents, activators, accelerators and scorch retarders.

We can improve elastomer's dynamic and mechanical characteristics by compounding some new ingredients or change the ratio of the existing one.

In the current study, previously supposed compound formula of SREI (which was previously studied and produced) was changed, rationally and some compounds were designed and produced. Afterwards, initial evaluation was performed after some physical and mechanical tests. For the targeted improvement, modified compounds were designed and manufactured. The standard test to achieve dynamic characteristics was implemented and the obtained results were compared. Finally, the effect of compound components was revealed.

2. Description of compounds

In this research, one supposed base isolator of SREI type, used in previous research [21,22], was based. This isolator was cylindrical and its structure and specifications are presented in Fig. 1 and Table 1.

Rubber compound of this isolator had been based on the natural rubber (NR) and consisted of the proportioning of raw rubber material with the vulcanization chemicals.

Basic compound ingredients are presented in Table 2. For the compound formula, part per hundred rubber (phr) is used. This is