Discussion on the methods to decrease Kd/Ks of rubber vibration isolation

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Abstract. Static and dynamic properties of rubber vibration isolation is the main problem in the design of rubber formula now. Relation between strength creep of rubber and Kd/Ks of isolation through the experiment. Kd/Ks decreases with the increasing of tensile strength at 200%. Some chemistry methods to increase TS at 200% are also conclusion, in order to make Kd/Ks of isolation better. This discovery shortens the period of rubber formulation development research ,and also reduces the cost of rubber vibration cost.

Keywords: Rubber vibration isolation; TS at 200%; Kd/Ks.

1. Introduction

Recently, usage of rubber vibration isolation in watercraft, car, spaceflight becomes more and more widely. And performance requirements of rubber vibration isolation become higher and higher. So research on the property of rubber vibration isolation have become the focus of engineers. At existing conditions, the focus of research on the property of rubber vibration isolation, mainly is the test of property of rubber vibration isolation. But in practice, this method is costly and consuming more time. The point of this paper is to find a method of decrease Kd/Ks of isolation so as to shorten the cycle of isolation development and cost.

2. Introduction of dynamic and static property of rubber vibration isolation

The deform which is recorded when the load reaches the rated load, is called rated deform. Static stiffness $K_s = \frac{1.1P - 0.9P}{S_1 - S_2}$. Dynamic stiffness is defined as isolation works at a defined frequency, static stiffness also effects the dynamic stiffness. Static stiffness is also regarded as stiffness when the frequency is zero. If load is changing, the stiffness is dynamic stiffness. Dynamic stiffness is greater than static stiffness, and dynamic stiffness increases with the frequency increasing. If Kd is greater than Ks, then working state is not consistent with loaded state far. At this condition, vibration is still transmitted through the isolation, without vibration isolation effect. This also explains that vibration isolation effect is better when Kd/Ks is smaller.

So in the process of isolation rubber formula design, it is resorted that Kd/Ks is smaller, given frequency range, the better the smaller Kd/Ks. When the working state is consistent with loaded state, vibration isolation is better. So for rubber formula design, it is important to reduce Kd/Ks of rubber vibration isolation as possible.

3. Advantage and disadvantage of traditional judgment method

With the difference of using space of rubber vibration isolation, its size, load and installation are also different, but it still requires low Kd/Ks, namely dynamic stiffness is close to the static stiffness. So low Kd/Ks is the main difficult question and of rubber formula design engineers.

Recently, design method of rubber vibration isolation is based on the former experience, after isolation is cured, static and dynamic properties of isolation are tested. It should be stopped when the property of isolation is consistent with technical resorts. This method is time-consuming and inconvenient ,up to now there is still no concrete thought for designers to guide the rubber formula design.

4. Interpretation of static data of rubber specimens

Traditional rubber formula design method is not relevant with property of specimen . In fact, strength property of specimen includes some dynamic properties. Through the interpretation of strength data (σ - ε cure), we can get some dynamic performance data. In the process of rubber formula test and isolation trial-production, some conclusion could be used for future rubber formula designers.

4.1 The same isolation are prepared with the same HA different formula rubber

In the experiment, strength at 200% is referred as the main parameter. Variation trend of strength at 100% with different rubber is not obvious. Strength at 300% is always used as the parameter to express the degree of cue and reinforcing effect. Around the elongation 300%, stress used for stretch crystallization is not so high, and stress is not relevant with elongation, So strength at 300% is not sensitive because of test error.

In the strength of different formula specimen with the same HA, From the initial point to the breakpoint, stress-strain cure has different courses. So figure with datas around 200% strain, as shown in figure 1.

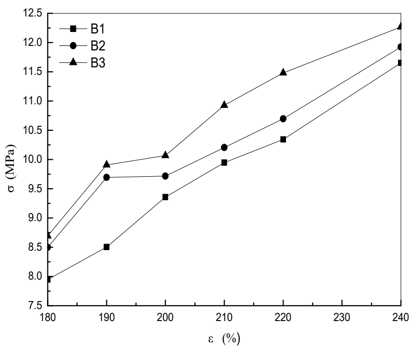

Figure.1 The cure of σ-ε

Calculation about the data cure in figure 1, stress difference is 10.25MPa-9.75MPa=0.5Mpa, it can be concluded that lines between the two points at cure B1,B2,B3 are parallel. The projection of lines on the horizontal axis, intervals are close. So it is concluded that the stress change of B1,B2,B3 is identical, namely dynamical stiffness changed less.

From the 10.25MPa point at the vertical axis, draw parallel lines with horizontal axis. The intersections of parallel lines with B1,B2,B3 cure project on the horizontal axis, then the corresponding strain change amounts are B3=210%,B2=212%,B1=218%. So in the premise of steady stress, the isolation prepared by the rubber whose strain is high has the low static stiffness. So the sequence of static stiffness is B3＞B2＞B1.

From the above analysis, the sequence of Kd/Ks is B3＜B2＜B1, this is consistent with the trend in table 1. Then it is concluded that for the same type rubber vibration isolation, isolation prepared from rubber with high strength at 200% has the low Kd/Ks.

A type isolation prepared from rubber B1,B2,B3 in figure 1, and properties are measured. The test data are shown in table 1.

Table.1 Kd/Ks and tensile strength at 200% of rubber

Table Head	Table Column Head	
	Strength at 200% /MPa	Kd/Ks

Table Head	Table Column Head	
	Strength at 200% /MPa	Kd/Ks
B1	9.357	2.22
B2	9.715	2.06
B3	10.376	1.91

From table 1, A type isolation is prepared from different formula rubber with the same HA. With the increase of strength at 200%, Kd/Ks of isolation reduces. A type isolation prepared from rubber with the highest strength at 200% has the lowest Kd/Ks.

Change range of static stress on the vertical axis, stress intersections of stress-strain cure of different formula rubber between the range are parallel. So it is concluded that lines projected on the horizontal axis are the same almost, namely dynamic stiffness changes little. But strain change ranges on the horizontal axis are not the same, namely static stiffness is different.

4.2 The same isolation are prepared with the different HA rubber

Strength at 200% is used to judge Kd/Ks of isolation when it is prepared from the same HA formula rubber. [1]So strength at 200% can be used to judge Kd/Ks of isolation qualitatively at some extent. This brings a question that how Kd/Ks of isolation changes when it is prepared from different HA formula rubber, and how to judge Kd/Ks of isolation.

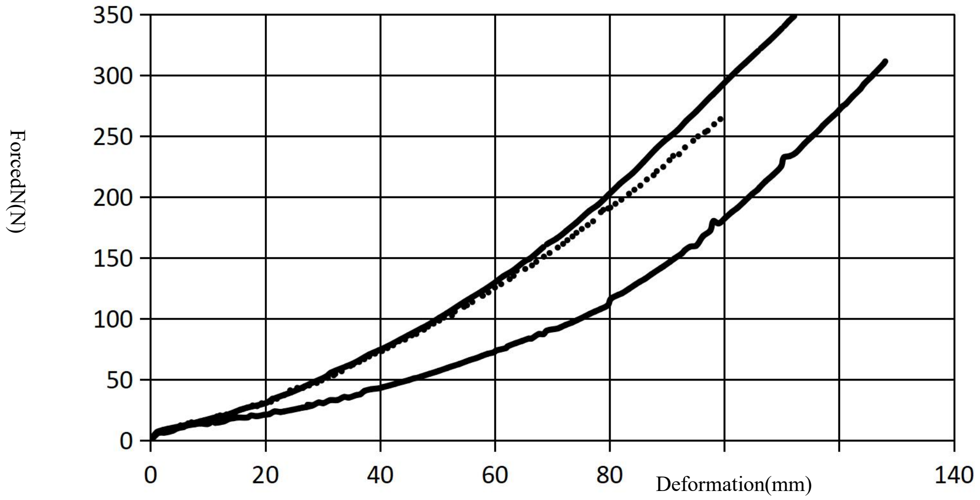

Figure.2 strength cure of rubber prepared for B type isolation

B type isolation is prepared from 50,55,60HAformula rubber. When rated load is steady, Kd/Ks are 1.48,1.63,1.87. Then analysis the strength cure, energy of 50HA rubber up to 200% strain is used as standard, the least squares cure fitting is adopted, its strength cure equation is

$y = -0.001x^2 + 0.798x + 5.761$,strength at 200% is 4.26MPa, then strength energy is $W = 2 \times 4.26 = 8.52$ unit.

The least squares cure fitting is adopted to 55、60HA compound ,their cure equation are $y = 0.015x^2 + 1.078x + 4.572$ and $y = 0.019x^2 + 0.925x + 5.766$ .When $W = 8.52$, x equals 1.398,1.250. So strength at 139% and 125% of 55HA and 60HA compound cure equal strength at 200% of 50HA compound cure. Then it can be concluded that with the increase of compound HA, Kd/Ks of isolation increases.

5. Methods to decrease Kd/Ks of rubber vibration isolation

5.1 Increase strength at 200% in order to decrease Kd/Ks of isolation

5.1.1 Rubber

Kd/Ks of isolations prepared from NR and NR/BR are 1.25、1.05, it is can be concluded that BR used in isolation is good for decreasing Kd/Ks. And Kd/Ks of isolation prepared from NBR is far larger than that prepared from NR. So it is concluded that Kd/Ks of isolation is low prepared from rubber whose structure is in order. And Kd/Ks of isolation is low prepared from rubber whose polarity is small.

Rubber is chosen by Mwand Mw/Mn[2], tensile strength becomes larger with Mw increases. But when Mw increases to the extent, the sum of secondary valence force between molecules is larger than chemical bonding force of main chain. At the effect of tensile force, chemical bonding has been destroyed before the sliding between molecules, then tensile strength is not relevant with Mw. Mw has some restrain effect on the tensile strength, so in order to guarantee high tensile strength , Mw of rubber should be larger than the critical value. It is suggested that 3.0～3.5×105 raw rubber is used.

Large proportion of oligomer part in raw rubber leads to decrease of tensile strength of rubber. When Mw is the same, tensile strength of narrow Mw/Mn raw rubber increases much greater than wide Mw/Mn raw rubber. It is suggested that $\overline{M_w}/\overline{M_n}$ 为2.5～3.0 raw rubber is used.

5.1.2 Cure system

At the premise of accelerator kind and amount at a certain consistent, Kd/ Ks of isolation decreases with the usage of sulfur increases. But tensile strength can be improved through the increasing of sulfur usage and traditional sulfur-accelerator system. In the process of rubber formula, Kd/Ks and tensile strength should be considered at the meantime through sulfur system to improve the property of isolation.

5.1.3 Enforcing filler

Experimental results show that fillers with larger particle size will reduce the Kd/Ks of the isolator. Some fillers, such as mica powder, which increase damping fillers, cannot be used in low dKd/Ks rubber formulations. However, fillers with larger particle size have poor reinforcement effect and low strength; fillers with smaller particle size have good reinforcement effect and large Kd/Ks. In soft rubber, when the amount of carbon black is 40-60 parts by mass, the tensile properties of the vulcanized rubber are better. Therefore, when adjusting the formula to improve the performance of the isolator through fillers, both dynamic-to-static ratio and tensile strength should be considered."

5.1.4 Softer

The addition of softeners will reduce the tensile strength of vulcanized rubber. A small amount of softener (generally not more than 5 parts by mass) can improve the dispersion of carbon black, and the tensile strength of vulcanized rubber may also increase. Different softeners have different effects on the properties of rubber and vibration isolators. For example, for the same quality of dibutyl phthalate and cycloalkane oil, dibutyl phthalate has a greater effect on the hardness, and cycloalkane oil has a greater amplitude of Kd/Ks reduction; trimethylbenzene ester can reduce hardness while giving the rubber a certain flame retardancy. Mechanical oil, industrial grease, etc. have a greater impact on the strength of rubber materials and can be used in large quantities in low-cost rubber formulations. High-viscosity oils, resins, and polymer oligomers can ensure high tensile strength of vulcanized rubber. Aromatic hydrocarbon oils have little effect on the tensile strength of non-polar unsaturated rubber, while paraffin oil has a greater effect; for saturated non-polar rubber, it is best to use paraffin oil and cycloalkane oil with unsaturation; for polar unsaturated rubber, it is best to use aromatic hydrocarbon oils and ester softeners.[2]

5.2 Other chemical methods

There are two ways to increase the fixed tensile strength: one is to increase the tensile strength of the rubber while the elongation rate remains unchanged; the other is to reduce the tear elongation rate of the rubber under the premise that the tensile strength remains unchanged. The methods for increasing the fixed tensile strength in chemical industry can be used to reduce the dynamic and static ratio of vibration isolators.

5.2.1 Methods for improving tensile strength

Rubber and resin blending, nitrile rubber and polyvinyl chloride, natural rubber and polyvinyl chloride blending can all improve tensile strength; 2) Chemical modification of rubber, adding reactive modifiers to the rubber material, through the interaction between the modifier and rubber and filler, to improve tensile strength; 3) Surface modification of fillers, using surfactants and coupling agents to improve the interfacial affinity between fillers and macromolecules can improve the mechanical properties of vulcanized rubber.

Taking into account the factors that affect tensile strength, there are several ways to improve tensile strength: 1) Increase the viscosity of the system to restrain the movement of macromolecular chains and consume energy at the crack front; 2) Improve the chemical structure of crosslinks in the vulcanized rubber network so that it can withstand higher loads; 3) Increase crystallinity and orientation, and the crystalline orientation can improve the strength of the vulcanized network and prevent crack development.

Methods for improving tensile strength at a fixed extension: 1) The larger the molecular weight and the narrower the molecular weight distribution, the greater the tensile strength at a fixed extension; Under similar molecular weight conditions, the polydispersity should be minimized to narrow the molecular weight distribution; 2) Rubber macromolecules with polar atoms or polar groups on the main chain have high tensile strength at a fixed extension; Crystalline rubber increases intermolecular forces due to physical nodes formed by crystallization, which also increases its tensile strength at a fixed extension; 3) Tensile strength increases with increasing crosslink density. Appropriately increasing the crosslink density of rubber materials mainly depends on the variety and amount of vulcanizing agents and accelerators. For example, quinoline, guanidine, and thiourea have higher activity. The tensile strength of vulcanized rubber is also higher. Compared with ordinary vulcanization systems, effective vulcanization systems and peroxide vulcanization reduce stress relaxation speed of natural rubber at 27℃ by nearly 60%; 4) Activated modification treatment of filler surface.

5.2.2 Reduce elongation at break

The addition of plasticizers and softeners will increase the elongation at break; under the premise of not changing the tensile strength and vibration isolator performance requirements, appropriately changing their types and reducing their usage can improve the fixed extension strength.

6. Summary

4.1 transform the mechanical problem of reducing the dynamic and static ratio of the vibration isolator into a chemical problem that is easy to debug the formula and facilitate the debugging of the rubber formula.

4.2 comparing the main body of the adhesive, choose a type of adhesive that is suitable for the required comprehensive performance when designing the formula.

4.3 comparing several methods to improve the dynamic and static ratio of vibration isolators, choose the method with better vibration isolator performance when performance requirements conflict.

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