Choice of Elastomeric Material for Buffer Devices of Metallurgical Equipment

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Abstract: This study sheds light on the materials (elastomers) which are used for buffer equipment production. One of the unsolved problems concerning shock absorption is the problem of optimal material choice for the shock absorber. It is the main problem examined in this study. We conclude that the material should be chosen in accordance with such characteristics as energy intensity rate, internal friction and rheological characteristic.

Key words: Buffer devices, elastomers, energy intensity, internal friction, shock absorbers

INTRODUCTION

The production and usage of elastomeric materials are becoming very common. We can observe it especially in fields such as mechanical engineering, transport, and building. Where the metallurgy of the elastomeric materials gets popular rather than slower. It can be explained by heavy-load conditions for metallurgical equipment components that have extreme exposure to temperatures and loads; not only useful (manufacturing) but also harmful loads are connected with imperfection in metallurgical equipment designing and operation.

The questions concerning the application of rubbers and rubber-like material for harmful loads absorption were treated more than once (Poturaev, 1966; Bolshakov, 2003). In these works describing "shock absorption" objects, there are information about rubber-metal elements application, its positive effects, its production and its usage of similar shock absorbers.

There is practically no theory which that shows the basis for shock absorber production. The majority of theoretical studies concerning the calculation of shock absorber are based on the determination of resilient member's stressed state in accordance with the stated loads. But we cannot agree with such an approach in principle because loads are more often are generated in the most elastic systems. First attempts to study the loads appearing processes can be seen in the works (Artyukh, 1997; Artyukh, 1999), but they are not enough.

Very often the subject of inquiry is metallurgical and other heavy equipment which always have not only heavy manufacturing load but also parasitic loads. These loads determine the strength and endurance of the equipment elements and units. It is impossible to avoid such loads but they can be decreased to a safer level with the help of shock absorption.

Shock absorber is an active equipment element to decrease the intensity of harmful loads that influence the equipment. Harmful loads are generated in the equipment lines of force due to different external actions. The most frequent external actions for metallurgical equipment are energy, deformation, temperature and also inertia exposure. Energy, or shock, exposure can be considered the most harmful one. It is possible to avoid overload and damages during this exposure only if the energy intensity (potential energy of deformation) of the elastic system that bears the shock is not less than the energy of the applied shock action. Undergoing the deformation of the system should possess enough rigidity not to allow the load exceed the permissible rate. The equipment elastic system can possess such properties due to such special active device as shock absorber.

The shock absorber operation principle is to change (increase) the energy intensity of the elastic system which undergoes a shock attack from without and to decrease the rigidity of the system undergoing the deformation.

To realize the shock absorption with the help of such special active devices, as shock absorbers is the easiest way. The latter should process certain equipment loading operating characteristics.

THEORY AND EXPERIMENT

Let us take a look at the load of certain metallurgical equipment and their certain units in accordance with the above-mentioned loading peculiarities. The most frequently occurring loading is "shock loading".
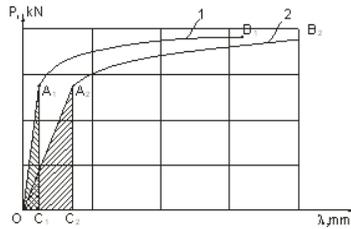
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Fig.1: Working characteristics of the elastic system: 1-System with no shock absorber, 2- System with shock absorber

Fig. 2: Compression-test diagram of polyurethane specimen adipren L167 ShA 95

Shock loading (energy loading): The examples of such load can be:

- Bridge crane tripping over the stop
- Ingot fall to the mill roller conveyer
- The case of feed (ingot) hitting the rolls of the mill when being nipped, etc

In all these examples, the elastic system (stop for the crane, roller of the roller conveyer, roll stand of the mill) undergoes the impact of the collision energy that comes from without. This energy turns into the elastic energy of the strain bearing the system shock. When the energy of the elastic strain is less than the energy of collision, the collision energy will be absorbed in the presence of the plastic strain of the system; and if the work of the elastic and plastic strains will be less than the collision energy, the failure of the weakest unit (crane stop, roller bearing, working roll of the mill) of the elastic system will occur.

Figure 1 shows two variants of working characteristics of the elastic system (strain-load diagram):

- System with no shock absorber
- System with shock absorber

They have the difference in the plastic strain energy. Area $\Delta\ OA_1C_1$ is the plastic strain energy of the system with no shock absorber. Area $\Delta\ OA_2C_2$ is the plastic energy of the system with shock absorber. In Fig. 1 we can see that the problem of the effective shock absorption is to exclude the failure of the equipment or permanent strain in its units. This can be achieved if the elastic strain energy (area $\Delta\ OA_2C_2$) is greater than the collision energy. Besides, the system loads should not exceed the admissible level.

The easiest way to exceed the energy intensity level of the elastic system is to implement an energy-intensive element, a shock absorber, into this system. The shock absorber (collision energy absorber) can be called a buffer. The main buffer designing task is to create a
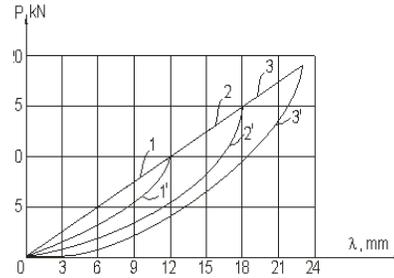
device with maximum energy intensity (in the condition of the reduced clearances). It is noted that we need a material with maximum specific energy intensity u Нм/м^3 for it (Artyukh, 2002). This value has stress dimension, Mpa:

$$u = \alpha \frac{\sigma_*^2}{E} \qquad (1)$$

Or $u = \alpha \varepsilon_*^2 E$ $\qquad (2)$

It is recommended to use dependence 2; all the values used in dependence 2 can be found experimentally in one experiment.

In this experiment, the mentioned parameters under the condition of compression of polyurethane test cylinders of $d_0 = 40$ mm and $l_0 = 40$ mm were determined. The cylinders' faces were lubricated to reduce the impact of friction on the rigidity quality. The specimens were tested on MI-20-UM equipment with the computer record of the compression-test diagram. The diagram of the compression under different loading conditions is shown in Fig. 2. In the experiment, a polyurethane specimen *adipren L-167* ShA95 was tested; it is commonly used in heavy and metallurgical engineering industry.

By using the compression-test diagrams (Fig.2), we can calculate a normal module of elasticity under the compression E_c. For the tested material we got a load-loading strain relation (close to linear), thus we can consider Hooke's law to be applied in this case. Therefore, a normal module of elasticity under compression can be found by the formula:

$$E_c = \frac{N.l_0}{\lambda.A_0} \qquad (3)$$

Here $N = P$-load for any point in on the loading portion. To calculate E_c, $N = 15 \times 10^3$N; $\lambda = 18 \times 10^{-3}$m-the specimen strain corresponding the assumed load:

$$A_0 = \frac{\pi d_0^2}{4} = 12{,}56.10^{-4}\,\text{m}^2$$

Using this data we found that $E_c = 40\text{МПа}$. Value ε_* can be found taking the condition of absence of the specimen permanent strains after unloading. Figure 2 show that the first and the second loading do not cause any permanent strains. The curves after unloading return to point 0, while in the third loading there is a permanent strain $\lambda_{\text{ост}} = 3\text{mm}$ after unloading.

Here, setting the step $\Delta\lambda$ it is possible to find experimentally maximum strain $\lambda_{\max}$, where $\lambda_{\text{ост}} = 0$, thus:

$$\varepsilon_* = \frac{\lambda_{\max}}{l_0} \qquad (4)$$

This experiment shows that small permanent strains $\lambda_{\text{ост}} \leq 0,4$ mm (it makes 1,0% of the specimen's height $l_o = 40$ mm) decrease with time and after staying without any load during 24 h completely disappear. As buffer devices undergo single rare impacts, it was agreed to determine $\lambda_{\max}$ not with $\lambda_{\text{ост}} = 0$ that caused difficulties due to the limited precision of measurements, but with $\lambda_{\text{ост}} = 0,4$ mm to within $\Delta\lambda = \pm 0,05$ mm.

In our experiment with polyurethane specimen *adipren L-167* we found that $\varepsilon_* = 0,32$. In our compression experiment factor a can be considered equal to $\alpha = 0,5$, as the energy is shown as a triangle area.

Let us note that $\alpha = 0,5$ is even stress distribution in the resilient member; it is the best distribution method that can be taken while buffer devices are produced. Using the mentioned data for *adipren L-167* we will get:

$$u = 0,5 \times 0,32^2 \times 40 = 2,05\text{MPa}$$

Here it is necessary to take into consideration that there is no important characteristic as specific energy capacity of the material in the list of polyurethane elastomer characteristics provided by producing companies. Therefore, this parameter was disregarded during the choice of the material and thus we can hardly expect any progress in this field.

The specific energy capacity selection of the elastomer cannot be simplified and reduced to modulus of elasticity selection as in case of rigidity increasing (i.e., modulus of elasticity increasing) the permissible strain decreases. Thus, for example, for the materials of *adipren* type we will receive:

- Adipren L-100 (E = 25 MPa; $e_* = 0,35$; a = 0,5) u = 1,53 MPa
- Adipren L-315 (E = 300MPa; e_*=0,10; a = 0,5) u=1, 50 MPa

Thereby the energy capacity gets smaller with both greater and smaller rigidity.
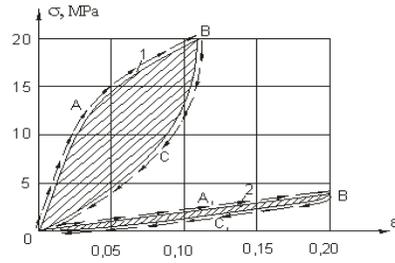

Fig. 3: Stress-strain diagrams of polyurethanes in compression

Buffer devices application sphere numbers a lot of cases when the resilient member of the buffer device is a spring of high energy intensity. The spring steels with such a parameter indeed compete with polyurethanes, but lose on a parameter as steel resilient members have uneven strain distribution (Polifke *et al.*, 2004; Jilin Daxue, 2003).

All the steels, including spring steels, are very rigid materials, that is why it is practically impossible to use them to make a resilient member or buffer which works in compression or shear and which can provide a load limitation to the equipment by permissible values. We will have to give the steel buffers such a shape that they work in torsion or bending. Here cases the strain distribution is uneven. For example, coil helical springs working in torsion have the resilient member stress state quality factor $\alpha = 0,25$, that is twice less than compressive elastomeric elements. The leaf springs working in bending on the basis of a beam scheme loaded with a concentrated force have the factor equal to 0,055 that is nine times less than for uniaxial compression. This gives the advantage to elastomers, first of all to high-strength and energy-intensive polyurethane elastomers, when buffer devices are produced (Jakop, 2006).

Moreover the spring steels have a very small internal friction, thus, the efficiency of such buffers is high. To make the energy dissipation of such buffers better, an additional friction element is installed; that makes the construction more complicated.

In polyurethane resilient members internal friction can be very high. During one loading cycle it is possible to dissipate up to 50…70% of energy accumulated by the buffer. Figure 3 shows stress-strain diagrams of polyurethanes of different rigidity in compression. OABCO diagram is for a rigid polyurethane, $OA_1B_1C_1O$ diagram is for a softer one.

Energy dissipation value in the interior of the material y, % can be found in the following way:

$$\psi = \frac{\int_0^{\varepsilon_*} \sigma_1 d\varepsilon - \int_0^{\varepsilon_*} \sigma_2 d\varepsilon}{\int_0^{\varepsilon_*} \sigma_1 d\varepsilon} \cdot 100\% \qquad (5)$$

Parameter *y* is changed for polyurethane within the limits of:

Table1:(Provide self explanatory caption)

Material	E, Mpa	ψ, %	δ	Loss of load, % during 60 min.
V8000 ShA65	7.5	8.0	1.10	5.2
V8000 ShA85	20.0	20.0	1.12	12.1
A16 ShA95	43.8	45.0	1.14	18.5
B16 ShA95	33.8	50.0	1.14	25.6
Adipren L100 M ShA90	9.5	12.0	1.09	13.0

$$10\% \leq \psi \leq 70\% \qquad (6)$$

In a number of cases this parameter can vary for buffer devices, for example, it is necessary to fulfill the condition $\psi \geq 60\%$ for cushions of railway vehicles. This parameter increases with the growth of rigidity of polyurethanes; that makes the choice of resilient member material easier.

Under ordinary temperature conditions all the polymeric materials, including polyurethanes, have such rheological effects as stress relaxation under constant deformation, the dependence of normal modulus of elasticity on loading rate. In the majority of cases these effects are unwanted in case of normal operating conditions of polyurethane products. Anyway, these effects should be taken into consideration while shock absorber with polyurethane resilient member producing.
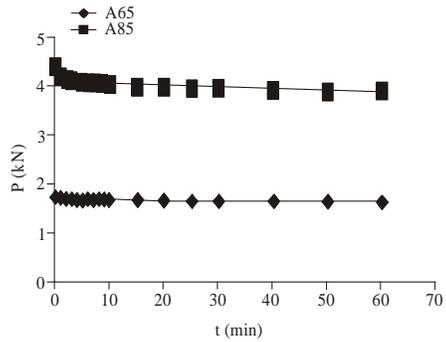
Metallurgical equipment has practically no static loading that is why the polyurethane member's rigidity turns out to be a bit higher than the one of the static tests. The dependence of modulus of elasticity on the strain rate reminds exponential dependence; with certain rate, the modulus value stops growing. It approaches asymptotically the limiting, or dynamic modulus of elasticity which is connected with a normal modulus of elasticity (static) through:

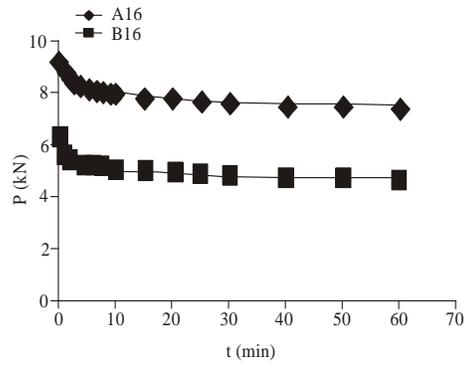$$E_\partial = E.\delta \qquad (7)$$

The value δ depends on the elastomer type and can be found experimentally.

In some buffer devices prestressing is used for improving the operating characteristics. The resilient member of such a buffer is compressed. The compressive strain keeps constant in the process of its operating; the force of compression gradually relaxes. The relaxation curve is close to the exponential curve, too. The relaxation process slows down with time.
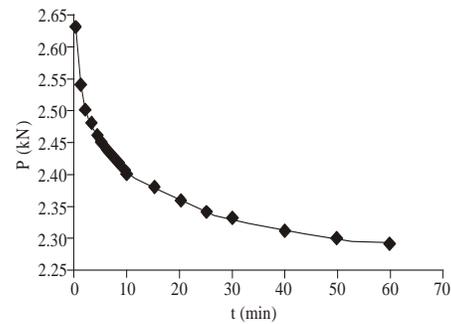
Table 1 has data concerning the test specimen of 5 different polyurethane types, and also the results of determination of normal modulus of elasticity E, energy dissipation parametery, hardening factor δ and relaxation of the load during 60 min. Relaxation curves are shown in Fig. 4a, b, c. Using the diagrams and Table 1, we can easily choose the material with minimal rheological effects. It is vibrathan V8000 ShA65 (Huber, 2003).

(a) Vibrathan 8000 ShA 65; ShA 85

(b) Adipren A16 ShA 95; B16 ShA 95

(c) Frost-resistant adipren L100M ShA 90

Fig. 4: Force relaxation in compressed specimens

CONCLUSION

While choosing a material for the buffer device resilient member, we should pay attention to the material with maximal specific energy capacity, maximal internal friction and minimal rheological effects. The parameters of the elastomers chosen should be taken under the real designing conditions.

The most appropriate materials for buffer devices resilient member producing from Table 1 are A16 (E = 43, 8MPa; ψ = 45%) and B16 (E = 33, 8MPa; ψ = 50%).

NOMENCLATURE

P load (kN)

α Resilient member stress state quality factor

σ_* Permissible limit stress (MPa)

ε_* Permissible ultimate strain

E Normal modulus of elastic material (MPa)

$E_{\text{д}}$ Dynamic modulus (MPa)

E_c Normal modulus of elasticity due to material compression (MPa)

u Specific energy capacity of the material (per unit of volume) (MPa)

σ_1 Equation of stress diagram load curve

σ_2 Equation of stress diagram unloading curve

ε^* Ultimate strain

N Normal force in the cross-section (N)

λ Strain of sample (m)

$\lambda_{\max}$ Maximum elastic strain (m)

$\lambda_{\text{ост}}$ Permanent strain (m)

A_0 Initial cross-section area of the sample (m^2)

δ Hardening factor

t Time (min)

ψ Energy dissipation parameter (%)

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