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ŁPW STEEL ARCH SUPPORT – DESIGNING AND TEST RESULTS

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Abstract

Increasingly difficult geological-mining conditions make it necessary to seek new and effective ways of securing roadways. The new types of support must meet very high strength requirements and must have very high load-bearing capacities. These two conditions were taken into consideration when an ŁPw type steel arch support was designed. High strength of the arches was obtained through using steel of improved mechanical parameters, while high load-bearing parameters were obtained through shaping elements of the support arches. The works were conducted within the framework of the targeted research project no. 6ZR8 2008 C/07012 undertaken by Huta Łabędy SA, Institute for Ferrous Metallurgy and Central Mining Institute between 2010 and 2012.

Key words

support, load capacity, research, project

1. INTRODUCTION

Continuous deterioration of geological and mining conditions in hard coal mines and, an increase in the load affecting the support are the result of several factors: the growing depth of mines, former exploitation, geological disturbances and rock mass tremors. Also, the use of workings of greater and greater cross sections, which is associated with the size of mining machinery and equipment has a significant influence on the increase in the load. In such a situation, it is necessary to use roadway supports of high load-bearing capacity parameters to provide a sufficient level of safety. It is also important to use the parameters of support fully, which may be obtained through improving the conditions of how individual support arches work, through the use of tight lining between the support and the rock, proper setting on the floor and proper setting against its sidewalls (Konopa, Sawka 1987; Pacześniowski 1997; Skrzyński et al. 1999). Additionally, in cases of a support consisting of yielding support arches it is important to use friction joints appropriately, according to the value, distribution and character of the load. The above mentioned issues are the result of economic reasons. Coal mines, adapted to the realities of the free market, are forced to lower their costs of production. It is one of the reasons for searching for, and testing new, more effective ways of securing roadways and for the full exploitation of the currently existing solutions. To meet these demands, designers and producers of supports constantly expand the range of available solutions to optimal supports to given geological-mining conditions. That is how a wide range of types of arches of a roadway support, made of different sizes of V profiles, and of steel of diversified mechanical parameters (Katalog…) have been developed.

A yielding steel arch support is a basic type of roadway support used in Polish coal mines. Its main element is a steel frame made of V-shape profile arches of the following weight factors: 25, 29, 32, 34 and 36 (weight of 1 meter of a profile). It is necessary to note that, at present, the most common ones are arches made of V29 and V32 profiles. Support arches have the biggest share of generating costs of supports since they are the heaviest elements. Thus, lowering costs of the support (both material costs and building costs), must be associated with reducing the number of support arches, as they have the biggest influence on the amount of steel used in the support. A massive share of the steel used in given elements of a support (per a linear meter of a support at 1-meter pitch) is shown in Figure 1. Figure 2, in turn, shows the distribution of material costs of particular elements in 1 meter of a support. As the presented graphs show, the simplest and most effective way to improve the cost effectiveness of the solutions applied and to lower the unit weight of a support is increasing the distance between arches, as their share both in the total price and the total weight of a support exceeds 60%. The aim can be achieved without losing anything of the load-bearing capacity of a support.

As it is seen, lowering the amount of steel used in a roadway support is tightly associated with its pitch. Increasing it without taking any additional action leads to lowering the load capacity of the whole support. In such cases, to maintain an appropriate level of safety, it is necessary to apply arches of greater load capacity – of improved shape or made of steel of improved mechanical parameters. Such an approach was chosen in targeted research project no. 6ZR8 2008 C/07012, undertaken between 2010 and 2012 by Huta Łabędy SA, Institute for Ferrous Metallurgy and Central Mining Institute.

One of the first stages was preparing, firstly, the chemical composition of a new grade of steel of high mechanical parameters and, secondly, the technology of rolling profiles made of the steel. The second stage includes designing new support arches made of the new grade of steel to use the high strength of the elements optimally. The scope of actions of given contractors is presented in the form of a scheme in Figure 3.

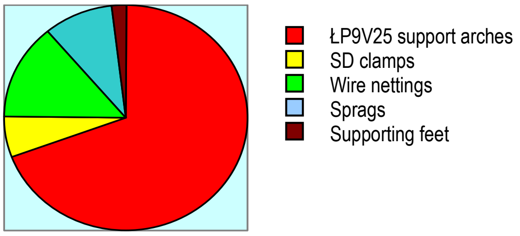


Fig. 1. Share of steel in particular elements in total weight of support (Rotkegel et al. 2005)

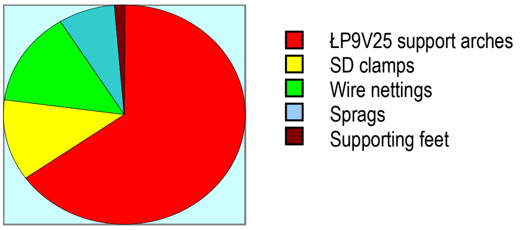


Fig. 2. Distribution of material costs of support per 1 meter of working (Rotkegel et al. 2005)

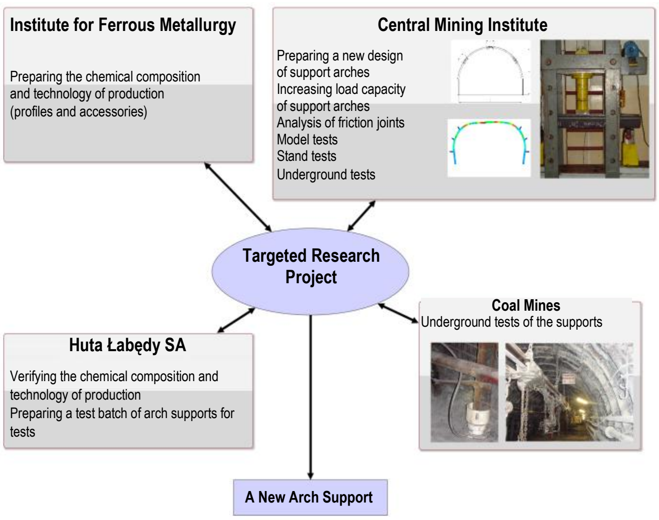


Fig. 3. Delegation of tasks undertaken within the framework of the targeted research project

2. NEW DESIGN OF SUPPORT ARCHES

The most important task undertaken within the framework of the targeted research project was designing a steel arch support of high load-bearing capacity with the use of the new grade of steel. As the characteristics of the work of yielding support arches ŁP shows, operating load capacity F_N (yielding) is 45–55% of the maximum load capacity of support arches F_{max}. In accordance to the standard of PN-G-15000/05, the extent of use of the maximum load capacity of support arches is expressed with the coefficient $k_4 = F_N/F_{max}$. Thus, to use the maximum load capacity of support arches properly, it is necessary to increase the values of both parameters which affect the 'enhancing characteristics' of stiffened and yielding arches. The concept of the actions is presented in Figure 4.

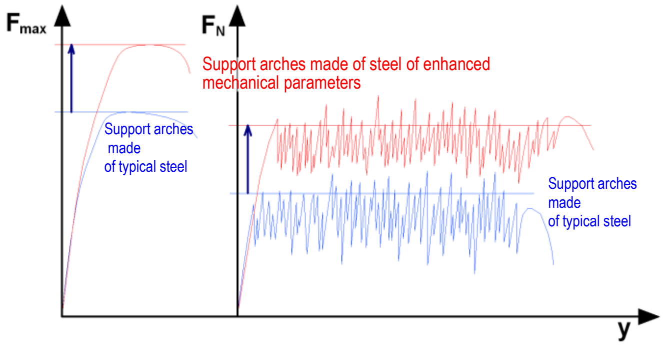


Fig. 4. Essence of enhancing characteristics of support arches: F_{max} – maximum load capacity of support arches (stiffened), F_N – operating load capacity of support arches (yielding), y – lowering support arches

Increasing the value of the load-bearing capacity of yielding support arches facilitates exploiting the strength of given elements (arches) more efficiently. Yet, when the strength is exploited excessively, it leads to stiffening support arches, as their load capacity and functionality disappear even after small deformations. It means that it is necessary to find an optimum value of coefficient k_4 – at which support arches have the greatest value of operating load capacity (F_N), and still retain their load-bearing capacity. The next issues are: shaping friction joints properly and choosing clamps to obtain the intended value of coefficient k_4.

To rectify the issues, numerous analyses and stand tests of friction joints were conducted. They included tests of both the straight segments of the profiles and the whole support arches. The research and analyses show an obvious fact that friction joints transfer bigger loads when the third clamp is used in a joint. An even greater increase in load capacity is observed when 'lens' effect (the gap between flanges of mating arches) is eliminated. The gap renders the contact and, as a result, the friction between the mating arches lessens in the area beyond the ends of the friction joints, as it is presented in Figure 5.

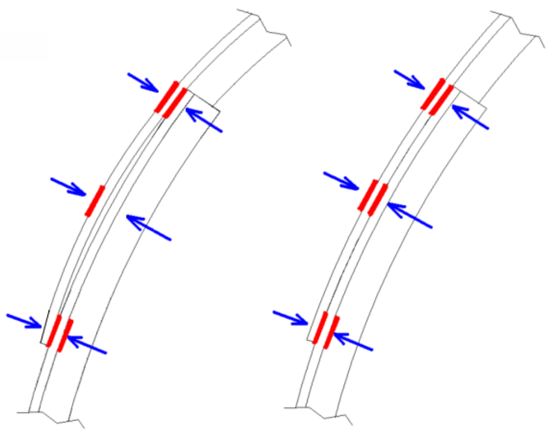
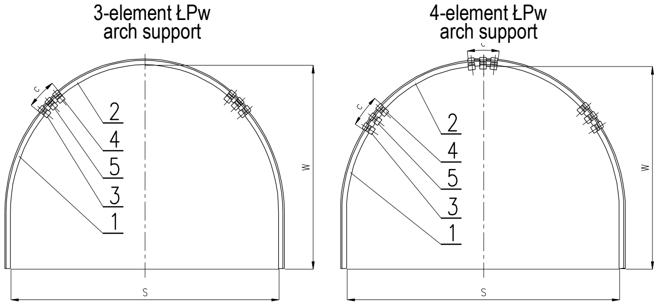


Fig. 5. Increase in the number of mating surfaces in friction joint through eliminating 'lens'

To change it and eliminate the effect, it is necessary to ensure the identical curvatures of mating elements. The newly designed ŁPw support arches meet this requirement. Identical curvature of mating roof arches and sidewall arches were used. It enabled using a third clamp in a joint and the improved performance of arches in comparison with ŁP support arches. The sizes of the newly designed support arches are comparable with the sizes of support arches of the ŁP type series, according to PN-G-15000/02, and include sizes 7–19 and profiles: V29, V32 and V36. Figure 6 presents a profile of support arches and type series of arches.



	Support arch markings	F	S	W	c			Weight of support arch without clamps		
					V29	V32	V36	V29	V32	V36
		m²	mm					kg		
3 elem.	ŁPw7/–/A	11,0	$4200^{\pm84}$	$3100^{\pm62}$	$500^{\pm25}$	$500^{\pm25}$	$500^{\pm25}$	277,6	313,6	346,7
	ŁPw8/–/A	13,0	$4700^{\pm94}$	$3300^{\pm66}$	$500^{\pm25}$	$500^{\pm25}$	$500^{\pm25}$	297,3	335,8	371,2
	ŁPw9/–/A	14,6	$5000^{\pm100}$	$3500^{\pm70}$	$550^{\pm28}$	$550^{\pm28}$	$550^{\pm28}$	316,2	357,0	394,8
	ŁPw10/–/A	17,4	$5500^{\pm110}$	$3800^{\pm76}$	$550^{\pm28}$	$600^{\pm30}$	$600^{\pm30}$	341,6	388,7	429,9
4 elem.	ŁPw7/–/4/A	11,1	$4200^{\pm62}$	$3100^{\pm62}$	$500^{\pm28}$	$500^{\pm25}$	$500^{\pm25}$	292,4	330,0	364,8
	ŁPw8/–/4/A	13,1	$4700^{\pm94}$	$3300^{\pm66}$	$550^{\pm28}$	$500^{\pm25}$	$500^{\pm25}$	316,4	352,4	389,6
	ŁPw9/–/4/A	14,8	$5000^{\pm100}$	$3500^{\pm70}$	$600^{\pm30}$	$550^{\pm28}$	$550^{\pm28}$	336,8	375,6	415,2
	ŁPw10/–/4/A	17,6	$5500^{\pm110}$	$3800^{\pm76}$	$600^{\pm30}$	$600^{\pm30}$	$600^{\pm30}$	362,0	408,4	451,6
	ŁPw11/–/4/A	19,7	$5800^{\pm116}$	$4025^{\pm81}$	$600^{\pm30}$	$600^{\pm30}$	$600^{\pm30}$	380,2	428,8	474,4
	ŁPw12/–/4/A	21,7	$6100^{\pm122}$	$4225^{\pm85}$	$600^{\pm30}$	$600^{\pm30}$	$600^{\pm30}$	396,0	446,8	494,0
	ŁPw13/–/4/A	23,9	$6400^{\pm128}$	$4425^{\pm89}$	$600^{\pm30}$	$600^{\pm30}$	$600^{\pm30}$	412,8	465,5	514,8
	ŁPw14/–/4/A	25,6	$6700^{\pm134}$	$4550^{\pm91}$	$600^{\pm30}$	$600^{\pm30}$	$600^{\pm30}$	424,8	478,8	529,6
	ŁPw15/–/4/A	27,6	$7000^{\pm140}$	$4700^{\pm94}$	$600^{\pm30}$	$600^{\pm30}$	$600^{\pm30}$	437,6	494,4	546,8
	ŁPw16/–/4/A	29,7	$7200^{\pm144}$	$4900^{\pm98}$	$600^{\pm30}$	$600^{\pm30}$	$600^{\pm30}$	452,4	511,2	565,2
	ŁPw17/–/4/A	32,2	$7500^{\pm150}$	$5110^{\pm102}$	$600^{\pm30}$	$600^{\pm30}$	$600^{\pm30}$	469,6	529,6	585,6
	ŁPw18/–/4/A	34,9	$7800^{\pm156}$	$5325^{\pm107}$	$600^{\pm30}$	$600^{\pm30}$	$600^{\pm30}$	486,8	549,6	607,2
	ŁPw19/–/4/A	36,8	$8000^{\pm160}$	$5465^{\pm109}$	$600^{\pm30}$	$600^{\pm30}$	$600^{\pm30}$	498,0	561,6	621,2

Fig. 6. ŁPw support arches: 1 – sidewall arch, 2 – roof arch, 3 – lower clamp, 4 – upper clamp, 5 – middle clamp

3. PARAMETERS OF PROFILES AND SUPPORT ARCHES

To use the new support and its elements safely it is necessary to know their basic strength parameters. When a new grade of steel for roadway arch supports is introduced, it is necessary to determine the strength of given profiles and the support arches made of it, as well as the efficiency of the connection of arches in friction joints.

3.1. Tests of straight segments of V profiles

The first of the tests conducted were bend tests (in two directions) of straight segments of V profiles, made of the new grade of steel. The tests are one of the basic methods to assess whether the profiles may be used as elements of a support. They also facilitate determining the maximum bending moment carried by the tested profiles (Rotkegel, Witek 2010; Pytlik 1999). The tests, conducted in accordance to PN-G--15000/09, consist of bend tests of profiles (in two directions). The range of the tests depends on the specific work of a roadway support. In an arch support under rock mass load, bending moments occur which operate in two directions. In the roof part a profile is bent ‘bottom down’, while in the sidewall part it is bent ‘bottom up’. The schematics of the tests and the test stand are shown in Figure 7.

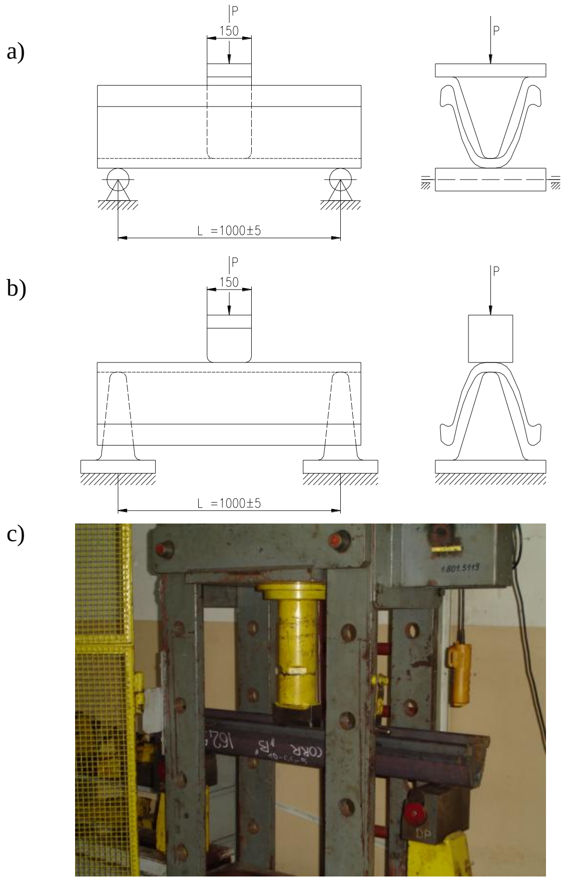


Fig. 7. Schematics of bend tests: ‘bottom down’ (a) ‘bottom up’ (b) of straight segments of profiles, and test stand (c)

The characteristics of V profiles made of the new grade of steel (bending of profiles under certain loads) were obtained during the tests. The graphs are shown in Figure 8. Results of the tests are presented in Table 1. Photo 1 shows the profiles after tests.

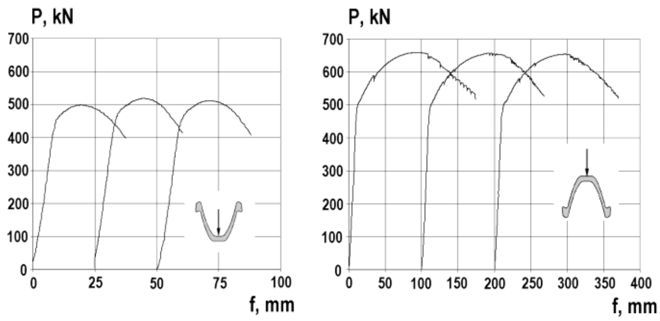


Fig. 8. Graphs of bend tests of V36 profiles made of steel of heat no. 162547. Bending direction – ‘bottom down’ (left) and ‘bottom up’ (right) (Pacześniowski et al. 2010)

Based on the test results, apart from determining the strength parameters of given samples, the optimum chemical composition of steel was chosen for further research. The composition facilitates producing profiles of high strength parameters at a minimum increase in the price of a new support.

Table 1. Results of bend tests of V36 profiles (Pacześniowski et al. 2010)

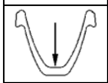
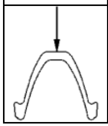
Bending direction	Heat no. 162547				Heat no. 162550			
	No. of sample	P_{max}, kN	f_{max}, mm	M_{gmax}, kNm	No. of sample	P_{max}, kN	f_{max}, mm	M_{gmax}, kNm
	10-66-4	498.3	19.3	124.6	10-55-12	472.5	22.7	118.1
	10-66-5	518.0	19.7	129.5	10-66-13	457.5	20.1	114.4
	10-66-6	511.7	21.4	127.9	10-66-14	465.6	20.2	116.4
	10-66-7	659.1	94.3	164.8	10-66-15	603.8	92.9	150.9
	10-66-8	657.1	92.9	164.3	10-66-16	609.3	92.8	152.3
	10-66-9	654.1	97.7	163.5	10-66-17	610.0	97.7	152.5

Photo 1. Profiles after bend test 'bottom down' (top) and 'bottom up' (bottom)

3.2. Tests of support arches

Stand tests of support arches were conducted in accordance with PN-92-G-15000/05 both for stiffened states and yielding states. During the tests, the support arches were loaded as it is shown in the schematics in Figure 9. During the test, a decrease in the height of the support arches (y), values of particular active loads ($F4$, $F5$, $F6$), values of particular passive loads ($F1$, $F2$, $F3$, $F7$, $F8$, $F9$) and changes in the position of points for measuring deformations were recorded.

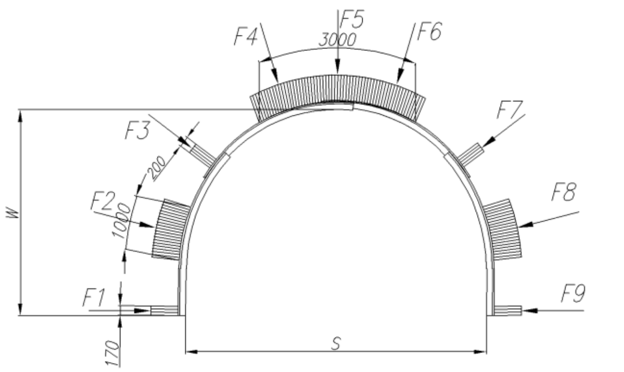


Fig. 9. Schematics of geometry and load of ŁPw/4/A support arches in test stand: *F*4, *F*5, *F*6 – active load; *F*1, *F*2, *F*3, *F*7, *F*8, *F*9 – passive load

3.2.1. Tests of stiffened support arches

The main aim of the tests was to determine the stiff characteristics of selected support arches from the type series. Based on the analysis of the obtained characteristics, it is possible to determine the load capacity of the tested support arches and calibrate numerical models to increase the accuracy of numerical calculations. Support arches with blocked friction joints, which excludes slide in joints, were tested.

The following types of support arches were tested: ŁPw8/V32/4/A, ŁPw10/V32/4/A, ŁPw12/V32/4/A, ŁPw10/V29/4/A and ŁPw10/V36/4/A. Figure 10 shows exemplary characteristics of stiffened support arches, and Table 2 – the results of the tests. The results were also compared in the form of a graph presented in Figure 11.

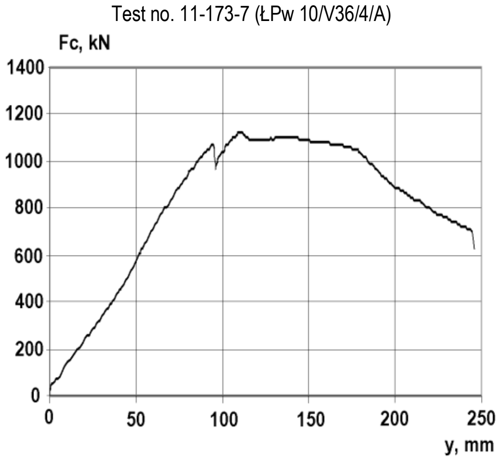


Fig. 10. Exemplary deformation characteristics of ŁPw10/V36/4/A support arches [10]

Table 2. Load capacity parameters of stiffened ŁPw/4/A support arches (Pacześniowski et al. 2010, 2011)

No. of support arches	Type of support arches	F_{max}, kN	*y*, mm	Visual inspection of support arches after test
11-173-1	ŁPw8/V32/4/A	1,362	104	Deformation of roof arch
11-173-2	ŁPw10/V32/4/A	1,004	103	
11-173-3	ŁPw12/V32/4/A	846	70	
11-173-4	ŁPw10/V29/4/A	850	94	
11-173-7	ŁPw10/V36/4/A	1,124	110	
10-267-1*	ŁP10/V36/4/A (modified)	1,151	198	

* test conducted in the first year of undertaking the project (2010).

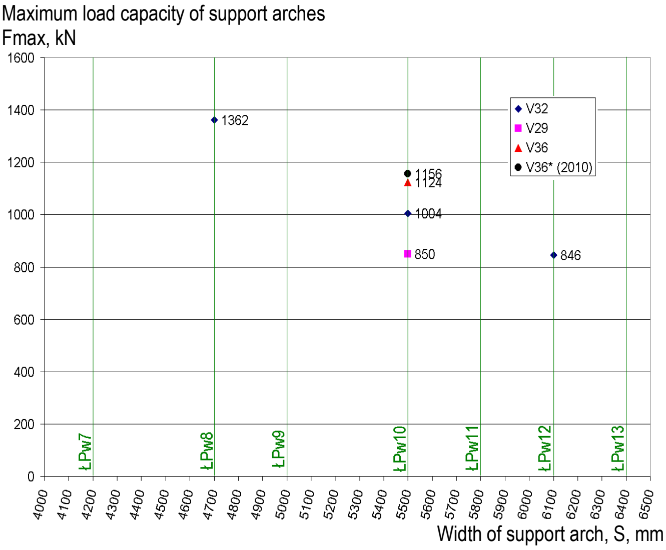


Fig. 11. Maximum load capacity of tested support arches

As results of the tests show, load capacity of support arches increases together with the use of bigger profiles and decreases as the support arches get bigger (Pacześniowski et al. 1997; Skrzyński et al. 1999). The conclusion is obvious, yet results of the tests simplify describing the changes quantitatively, as it is shown in a graph (Fig. 11).

3.2.2. Tests of yielding support arches

Tests on yielding support arches are particularly important for determining the operating characteristics of support arches. It is, among others, due to the fact that modelling conditions similar to the ones in a working environment are projected during the tests.

Testing the load capacity of yielding support arches is conducted in a similar way as it is in cases of stiffened ones. The difference is that yielding friction joints are retained. The aim of such tests is to check the performance of a support and determine the operating characteristics of support arches together with their load capacity. Within the project, 10 tests of support arches were conducted (Pacześniowski et al. 2011). The tests were conducted for different numbers of clamps in friction joints and for selected values of the torque of tightening nuts. Photo 2 shows support arches built up in the test stand. ŁPw10/V29/4/A and ŁPw10/V36/4/A type support arches were tested. The results of the tests – exemplary characteristics are presented in Figure 12, and the collection of load capacity values is shown in Figure 13.

Photo 2. ŁPw support arch in test stand during tests

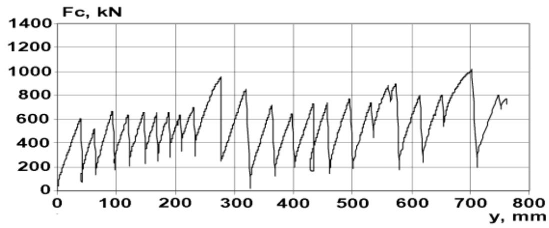


Fig. 12. Operating characteristics of ŁPw10/V36/4/A yielding support arches – two clamps per joint, the torque of tightening nuts M_d = 450 Nm (Pacześniowski et al. 2011)

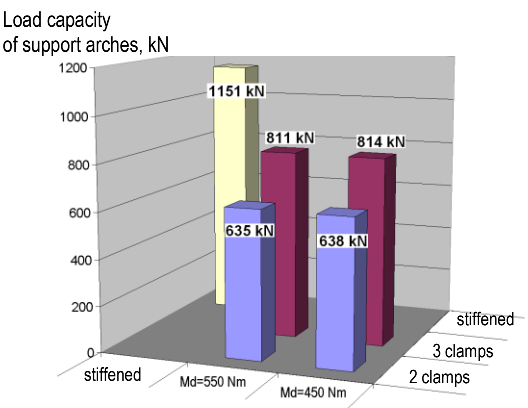


Fig. 13. Average results of tests of ŁPw10/V36/4/A support arches: stiffened joints (yellow), with two clamps in each joint (blue), with three clamps in each joint (purple)

Based on the analysis of the load capacity values of support arches, it can be observed that the values of the torque of tightening nuts of clamps, in the analysed range, barely influences their load capacity. A much stronger influence is shown when a third clamp is used.

3.2.3. Model tests of support arches

An important method to determine the load capacity parameters of a support, which can be used at the designing stage, is numerical analysis. It is most often conducted with the finite elements method (FEM) (Chmielewski, Nowak 1996; Cook et al. 2002). From the user's point of view, modelling in contemporary MES programs e.g. COSMOS/M (COSMOS/M… 1999; Rusiński et al. 1994) used at Central Mining Institute, or RAMA 3D (Grajek 2000), is reduced to entering the geometry of the tested objects and setting the parameters of its elements. The parameters include: properties of materials and cross-sectional parameters. The geometry can be set by creating it with computer software, or by importing a 3D image from CAD software, e.g. AutoCAD or ODRZWIA (Rotkegel 2003). Cumbersome discretization, especially in cases of complex models, is conducted with the software automatically, but under the user's control. Such a modelled system is then set and loaded in a way which reflects real conditions. The calculations show, most of all, the distribution of reduced stress, and the object deformation maps, the relative deformation of elements, the values of internal forces and the reaction of supports (Chmielewski, Nowak 1996; Dyląg, Jakubowicz, Orłoś 1996).

Conducting strength analyses of support arches requires building new models every time, both the shape and the cross-section parameters of the arches. Moreover, it is necessary to assume appropriate material parameters. Modelled support arches are set and loaded according to the scheme of testing support arches presented in PN-G-15000/05 or according to the load distribution in a given working environment e.g. in a separate analysis.

As a result of the conducted analysis, indicators of the load capacity of support arches made from the new grade of steel were obtained. The indicators are shown in Figure 14.

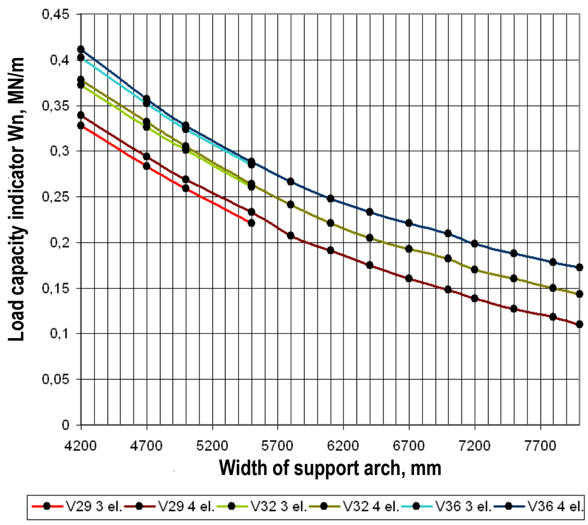


Fig. 14. Load capacity of support arches made of S550W steel for different sizes of V profiles

3.3. Underground tests and observations

Based on the stand tests and model tests, it can be concluded that the support arches work properly and their load-bearing capacity parameters are high. Thus, it was possible to conduct underground tests for the support arches made of the new grade of steel, to check whether they worked properly. The underground tests were conducted, based on methodology developed at Central Mining Institute (Prusek 2008), in sections of entries. In the test sites, measuring bases were installed on support arches made of the new grade of steel and on the support arches made of typically used steel. During the tests, load of support arches, yield in friction joints, as well as vertical and horizontal convergence and floor heave were recorded. Rock mass surrounding the working in the test site area was analysed with the available methods (Kuziak et al. 2012).

Three coal mines were chosen for the tests: Bogdanka SA, Bobrek-Centrum and Jas-Mos. The tests were conducted on different designs of support arches – newly designed ŁPw support arches, ŁPSC support arches used in LW Bodganka SA and SPŁ support arches. This facilitated gathering more information on the performance of different types of supports made of the new grade of steel.

The newly designed support arches were verified positively, as well as the previously used support arches (ŁPSC and SPŁ types) made of steel S550W. The tests confirmed the high load capacity of support arches made of the 2nd generation steel with increased mechanical parameters. It means they can be successfully used to secure roadways in difficult geological-mining conditions: the growing depth of mines, former exploitation areas and geological disturbances. Photos 3–5 show the support and the test sites in the coal mines.

Photo 3. ŁPw support arches built up in test raise 3, seam 504, Bobrek Centrum coal mine (Kuziak et al. 2012)

Photo 4. ŁPSC (of S550W steel) support arches built up in gate road 6/VI/385, seam 385, LW Bogdanka SA (Kuziak et al. 2012)


Photo 5. SPŁ6.8-7.2/3.5/V29 (of S550W steel) support arches built up in gate road 3-Z1,Z2, seam 510/2, Jas-Mos coal mine (Kuziak et al. 2012)

4. SUMMARY

Within the framework of the undertaken targeted research project, a new grade of steel and a new design of support arches of high load-bearing parameters were prepared. The parameters were obtained due to the use of S550W steel of higher yield point and strength in comparison to the materials used so far, as well as (in the case of ŁPw support) modifications to the shape of a profile of support arches. The idea of the modification is to unify curvatures of mating roof arches and sidewall arches to obtain better performance characteristics of support arches. The support of the new grade of steel passed all the tests, including stand tests and underground tests in the following coal mines: Bogdanka, Bobrek--Centrum and Jas-Mos.

Taking into consideration the above mentioned facts, it may be concluded that the newly designed steel arch support may be successfully used in mines, especially to secure workings in difficult geological-mining conditions where high load-bearing parameters are required.

Source of funding

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