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Material and Geometric Aspects of SB4 Spring Clips Affecting Their Performance

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Summary

The article describes the requirements for SB4-type rail spring clips applied for railways before the spring clips are officially approved for use. Two basic aspects of spring clips are discussed: i.e. the material aspect (chemical composition, heat treatment, microstructure, and decarburization) and the aspect of geometric shape. Both of these aspects have a major impact on the performance of the end product. The article features examples of measurement results concerning selected dimensions of a batch of spring clips that did not meet the applicable requirements. It is an introduction to a series of publications presenting research on the influence of material composition and geometry of a product on its clamping force, stiffness, elasticity curve, and assembly strength.

Keywords: rail fastening, spring clip, dimensional measurements, hardness tests

1. ntroduction

The application of spring-type systems of rail fastening to pre-tensioned concrete sleepers on railway tracks increases the hardness and reliability of the structure and improves the safety and convenience of travel. Contemporary fastening systems are characterised by effective vibration damping [7] and comply with the essential requirements under the relevant applicable legal acts, standards, and international regulations [1, 16, 17] at the same time, especially when it comes to the clamping force (pressure) exerted by rails on the underlying structure.

To make sure that the required clamping force is exerted on the underlying structure and that the rail is able to change its shape flexibly in the horizontal plane under the impact of lateral forces, a spring clip, as part of the fastening system, needs to comply with certain specific requirements. These requirements should consider, in particular, the aspects concerning the material the spring clip is made of and the geometric aspects, related to the process of shaping the spring clip in accordance with the design and at the required level of accuracy.

2. Manufacturing of spring clips

Spring clips are manufactured by means of heat bending. The manufacturing process starts from straightening circular steel bars of the required diameter and cutting them into sections of the length corresponding to a defined spring clip type. If the manufacturing of spring clips involves the use of bars of a larger diameter than required, it is necessary to draw the bars used in order to obtain the required diameter of their cross-section.

The next stage is induction heating of the cut bar sections up to the austenitization temperature. The heating time depends on the bar's diameter (in the case of manufacturing SKL 12 clips of 13 mm in diameter, this time is approx. 10 s). After heating, the steel bars are placed in the dies of the press brake and formed until they are shaped as required. Then, the formed clips are quenched in a cooling medium, usually in water or oil, for about 10 minutes. After quenching, they cool down naturally, and then are subject to medium tempering at about 400°C. The main purpose of tempering is to improve the product's strength, elasticity, and durability, and the duration of tempering

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is about 90 minutes. The final stage involves treating the clips with anti-corrosion oil or coating them with paint [4, 5].

3. General material requirements and shaping of the microstructure of steel earmarked for spring clips for track superstructure

The most important quality of good springs is their ability to return to their original shape after becoming loaded and unloaded. This condition can be met only by materials characterised by:

1) a considerable range of elastic deformation, meaning an elasticity limit as high as possible,
2) high plastic properties, so that when the elasticity limit is exceeded, the occurring permanent deformation does not damage the product,
3) a high static strength,
4) a considerable fatigue strength [18].

The strength properties and the elasticity limit in spring steels depend mainly on the carbon content, which can range approximately from 0.4% to 0.7%. The main alloy element in this group of steels is silicon, added in amounts of even up to 2% of the total content, causing the elasticity, plasticity, and tensile strength limits to increase. On account of the limited hardenability, the application of silicon spring steels is limited to small-profile elements. In order to increase the hardenability of silicon spring steel, the process of melting involves the incorporation of manganese of up to 0.9% of the total content. Such a chemical composition translates into a microstructure able to comply with the material requirements set for spring clips.

Spring steels, like other types of steel, have the content of contaminant elements – like phosphorus and sulphur – monitored. Steels containing phosphorus tend to be characterised by blue brittleness, are coarse-grained, and segregated. In the case of sulphur content, MnS sulphates and low-melt FeS sulphides are produced, limiting the potential for hot plastic formation and deteriorating the fatigue properties of steel. The requirements for the material used to manufacture spring clips determine that the average amount of each inclusion – including sulphates – should not be greater than the amounts given in reference no. 3 of PN-H-04510:1964 [13].

Somnath et al. [15] examined the impact of the chemical composition of spring steels on the potential occurrence of defects resulting from the heat treatment of steel. They monitored the inclusions arranged in strips along the direction of rolling, typical of steels with a chemical composition rich in silicon and manganese. The tendency to decarburize and cracks nucleation near the strips of non-metallic inclusions was observed. Similarly, Labisz et.al. [8] showed that the spring steel material quality assessed based on the presence of non-metallic inclusions has a crucial importance to the long-term use of a spring clip with a track. An interesting fact is that the authors found no impact of the purity of steel on its hardness.

Formation of the microstructure depends on the applicated heat treatment processes. This is also what the mechanical properties of the input material and the end product's compliance with the set requirements depend on. Depending on the grade of the steel in use, spring steel heat treatment mainly involves the process of austenitization at 800÷870°C and quenching in oil or water, followed by medium tempering at the temperature range of 380÷520°C. Ensuring the right conditions of heat treatment is extremely important since an excessively high annealing temperature of steel before cooling leads to material overheating and cracking, which is unacceptable in the case of products subject to fatigue, e.g. spring clips.

The fatigue strength of steel also depends strongly on the surface layer structure [2], which affects both the heat treatment and finishing processes. Surface decarburization of steel is also unacceptable since the surface of the product is characterised by a lower elasticity limit, which means it is not possible to obtain the appropriate mechanical properties. It is necessary to mention that the incorporation of alloy additives, i.e. silicon improving the elasticity properties or manganese improving the hardenability, contributes to the process of decarburization. The degree of surface decarburization needs to be therefore monitored in these elements by all means. A naked-eye inspection of the condition of the surface makes it possible to detect any visible surface defects, which may be a result of incorrect finish treatment.

Steel 50S2 is quenched in water or oil at 870°C and tempered at 460°C; steel 40S2, in turn, is quenched in water at 840°C and tempered at 430°C. Such heat treatment processes should result in the desired microstructure of tempered martensite, one that guarantees the required mechanical parameters. The quality certificates provided by the suppliers of the materials that spring clips are made of should always feature detailed information not only about the chemical composition but also the applied heat treatment and the finishing processes, and the basic mechanical properties.

The grade of the steel used to manufacture spring clips depends on local requirements and product type. In Poland, according to the ID-109 guidelines [17]. SB-type spring clips should be made of a steel bar of the diameter of 16 mm, made of steel 50S2 (Table 1), hot-rolled or hot-drawn. Some manufacturers of SB4-

Table 1

The chemical composition of steel according to PN-H-84032:1974 [14] and PN-EN 10089:2005 [9] applied with spring clips in accordance with the requirements of PKP PLK S.A.

Steel symbol	C [%]	Mn [%]	Si [%]	S_{max} [%]	P_{max} [%]	Ni_{max} [%]	Cr_{max} [%]
50S2	0.47÷0.55	0.60÷0.90	1.50÷1.80	0.04	0.04	0.40	0.30
40S2	0.35÷0.42	0.60÷0.80	1.50÷1.90	0.04	0.04	0.40	0.30
38Si7	0.35÷0.42	0.50÷0.80	1.50÷1.80	0.025	0.025	–	–

Table 2

The chemical composition of steel 48Si7 applied with SB4 spring clips [6]

C [%]	Mn [%]	Si [%]	S_{max} [%]	P_{max} [%]	Ni_{max} [%]	Cr_{max} [%]	Cu_{max} [%]
0.46÷0.53	0.50÷0.80	1.60÷2.00	0.025	0.025	0.40	0.40	0.1

type spring clips also use, in line with the reference documents [6], steel graded as 48Si7 (Table 2), with a chemical composition similar to that of steel 50S2.

The microstructure of a spring clip is assessed with the use of a metallographic microscope. The microstructure of a spring clip should feature fine-grain martensite and correspond to standards 1÷4 according to scale 3 in line with PN-H-04505:1966 [12] (percentage content of martensite in the structure – at least 97.5%, scale 8, standard 3). In addition, the martensite should be tempered (in the form of sorbite), with no needle-shaped remains (Fig. 1).

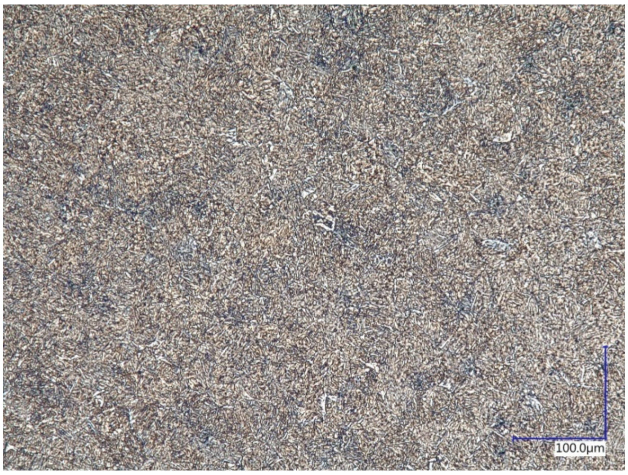

Fig. 1. The microstructure of steel 48Si7 in an SB4-type spring clip, hardness of 42.2 HRC [photograph by M. Ostromęcka]

Carburization depth measurement according to [15, 17] is also performed by means of metallography, in line with PN-EN ISO 3887:2018-03 [10]. Carburization can be whole-scale, which results in ferrite grains remaining near the surface of the product. It can also be partial. Then, a ferrite matrix can be seen in the product. The total depth of carburization after bending and quenching, determined on the basis of the diameter of the spring clip's steel bar, should not be greater than 0.20 mm (Fig. 2). Excessive decarburization may result in a range of defects, including microcracks, which are shallow and minor at an early stage of product use, but continue to propagate over time. In the case of spring clips required to display a certain level of fatigue strength, this is of great importance.

Fig. 2. Measurement of decarburization in steel 48Si7 [photograph by M. Ostromęcka]

The appropriate microstructure of material ensures that spring clips meet the required mechanical properties, e.g. hardness. Hardness tests are performed using Rockwell's method, according to the requirements PN-EN ISO 6508-1:2016-10 [11], after removing the top layer of 0.5÷1.0 mm in thickness from the indicated part of the clips (Fig. 3) or on their cross-section. The measured hardness should be within the range of 42÷46 HRC. The removal of the top layer to measure the hardness aims to prevent measurement of the decarburized layer, which may remain near the surface. An incorrect value of hardness is usually a sign of wrongly performed heat treatment.

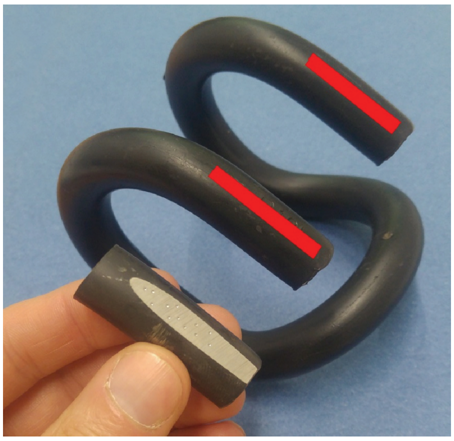

Fig. 3. An SB4 spring clip with the hardness measurement place marked in red and a ready sample with post-hardness testing traces [photograph by A. Aniszewicz]

4. Geometric requirements for SB4-type spring clips

The shape, dimensions, and construction tolerances of spring clips should be checked for their compliance with PKP PLK S.A.'s requirements defined in the Id-109 guidelines [17] by means of shop measurement tools and gauges.

Performing direct measurements and checks of SB4 spring clips strictly specific dimensions created by means of thick rods 3D bending is quite problematic. During such measurements, a major challenge is connected with the occurring irregularities, i.e. swelling and ovalisation of the rod ends cross-sections (appearing usually at the first stage of the manufacturing process, i.e. while cutting the rod to a specific length) or the twisting and curvature of theoretically straight clip ends. These are just some of the many uncategorised irregularities which have a huge impact on the values of the results of geometric measurements, and – therefore – on the assessment of the end product's compliance with the relevant guidelines.

The measurements of SB4-type spring clips, monitored for their compliance with the relevant requirements, i.e. "*a*", "*b*", "*e*" and "*f*", are presented in Figure 4. The radii of bending the input rod into 3D and parallel curves are also tolerated dimensions (but it is difficult to perform such a directly measurement, by means of shop tools and gauges), although they have not been considered in the incomplete test report according to appendix 6 to the ID-109 guidelines [17]. However, there are results of curves measurements and bending radii, measured by means of a contactless method with the use of a 3D scanner, revealing insufficient accuracy in the manufacture of clips (the deviations in the geometric shape of SB4 spring clips reached 32 mm at a construction tolerance of ±2 mm) [3]. The results of measurements of dimensions "*b*" and "*e*" also exceeded the adopted construction tolerance ranges.

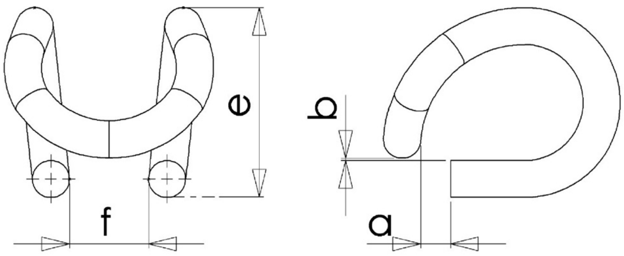

Fig. 4. Dimensions "*a*", "*b*", "*e*", and "*f*" of an SB4 spring clip, subject to measurements in accordance with the requirements of PKP PLK S.A. [fig. by A. Aniszewicz]

During the measurements of SB4-type spring clips geometry to qualify them for testing, irregularities are discovered quite frequently. They usually involve exceeding the tolerance range for dimension "*b*". Table 3 includes the results of dimensions measurements "*a*", "*b*", "*e*", and "*f*" of SB4 spring clips. Since the tolerance range for dimension "*b*" was found to be exceeded, the batch of the measured clips was rejected.

Table 3

Measurements of selected dimensions of a rejected batch of SB4 spring clips

Nominal values of the measured dimensions [mm] according to [17]		Measured values of the considered dimensions [mm] / sample number								Measurement uncertainty [mm]
		1	2	3	4	5	6	7	8	
b = 1	±0.5	0.2	0.1	0.3	0.3	0.5	0.2	0.3	-0.2	0.2
e = 82*	±2	82.2	82.2	82.3	82.4	82.3	82.5	82.3	82.3	0.2
f = 34*	±1	33.3	34.4	33.6	33.6	35.0	34.0	33.9	33.9	0.2
a = 13	+2	14.2	14.4	14.3	14.5	14.1	13.8	13.8	14.5	0.4

* The values of the considered dimensions are the average of two measurements [authors' own work].

5. Conclusions

Taking into account how a spring clip is fitted in a rail fastening system, it can be expected that if the value of dimension "*b*" is too low, it may cause an increase in the clamping force (pressure) exerted by rails on the underlying structure; if this value is too high, in turn, the force in question will decrease. It is reasonable to consider if the technological process of manufacturing clips is able to guarantee the manufacturing accuracy as provided for in the guidelines [6, 17]. Basically, the final shape of SB-type spring clips is the result of high-temperature formation, and the processes of quenching and tempering may have a significant impact on the occurrence of stress in the input material or relaxation of the input material, which may lead to material deformation.

For these reasons, some modifications in the applied manufacturing process should be considered.. At the same time, there is the question concerning the degree to which the accuracy imposed under the requirements [6, 17] for dimension "*b*" really affects the performance of spring clips. The tests carried out at the Railway Institute have not proven that irregularities in dimension "*b*" always affect other parameters defined in tests listed in the relevant documents [6, 17]. The issue remains opened and needs verification. The following steps in the further tests of SB4-type spring clips are suggested:

1) determination of the influence of dimension "*b*" of SB4 spring clips on their performance,
2) classification of the geometric irregularities occurring in spring clips,
3) development of an appropriate methodology ofgeometric dimmensions measurement, considering the existing irregularities and inconsistencies,
4) review of the guidelines in the area of the dimensions and shape of clips and of the recommended testing methodology.

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