Zarządzanie Przedsiębiorstwem. Enterprise Management
Volume 21 • Number 1 • March 2018 • pp. 21–25

SELECTED ASPECTS OF PRODUCTION CONTROL A CRANKSHAFT WITH A FREE FORGING METHOD TR

Andrzej Pacana, Karolina Czerwińska

Politechnika Rzeszowska im. Ignacego Łukasiewicza

Corresponding author:
Karolina Czerwińska
Politechnika Rzeszowska im. Ignacego Łukasiewicza
al. Powstańców Warszawy 12, 35-959 Rzeszów, Poland
phone: (+48) 502338775
e-mail: ktczerwinska@vp.pl

Keywords
forging, crankshaft, free forging by TR method.

Abstract
The quality evaluation shall be the primary objective of acceptance testing of forgings for crankshafts. This paper presents technological issues concerning the production of crankshafts. It also characterizes and presents the scope of application of free forging and discusses the properties of steel used in crankshafts. The research part of the paper includes the analysis of selected test methods for determining the quality of forgings intended for crankshafts.

1. Introduction

Quality management is one of the most important management areas in an enterprise that wants to stay on the market and be competitive. Manufactured products as well as offered services should be qualitatively adapted to the clients' requirements [2, 7, 13]. When defining the term quality, it can be stated that it is a set of features of products or services that make the customer satisfied. For this reason, companies take various actions to meet customer requirements and deliver what they need at a given moment, eliminating products that are not compliant, as well as eliminating compatibilities in production processes [1, 11].

The requirements placed on the crankshafts require the use of appropriate production technologies, including the smelting and casting of steel, forging, quality heat treatment and mechanical treatment. Given the complex shape as well as the high requirements in terms of dimensional accuracy, the most difficult stage of the production process is the final mechanical treatment. The course of this stage of the production process largely depends on the parameters obtained by the product in the stages preceding mechanical treatment. These product parameters include the size of the forged product after forging, the dimensional variations during pre-treatment and quality heat treatment, during shaft straightening operations, and the residual stresses in the machine-to machine shaft [8]. The complexity of the causes of discontinuities in forgings makes their diagnosis very difficult. One of the methods of testing finished castings is destructive – strength testing, which is the basic source of information necessary to make a decision on acceptance of the tested object.

The free forging process consists in a deformation of the metal between the tools, which allows to flow in several arbitrary directions (Fig. 1a). If the flow of metal is partly restricted by tools, then forging is called semi-liquid (Fig. 1b). For this type of forging, suitable shaping anvils and various tools are used to shape the piece of product (e.g. crankshafts or crankshafts) [9].

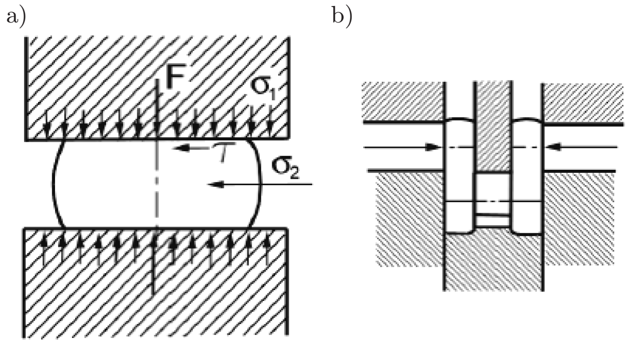

Fig. 1. Diagram of forging [12]: a) free, b) semi-liquid.

2. Characteristics and scope of application of free forging

The above forging methods shall be distinguished from die forging in which the material takes on a consistent shape with the forging method due to a complete restriction of the material flowing through the sidewalls of the tool used [10].

Free forging is used in the production of small batches or when making heavy forgings. Using this method makes it possible to produce a forged part of any weight. Small forgings are made from previously rolled batches, while large forgings are made from ingots. The maximum weight of ingots for open die forgings is 500 megagram [9].

Free forging is used in the following cases [14]:

- in unit production, where it is not cost-effective to make matrices,
- for the pre-forming of ingots of alloyed steel or alloys with special forged and slab properties,
- forgings whose weight and dimensions exceed the production capacity of the heaviest matrix units available,
- for the refurbishment of workshop tools and equipment,
- in the manufacture of forged bars of alloy steel or alloys with special properties, and of steel of the normal grades, where the section of the bar to be ordered is not covered by the rolling program,
- when making spare parts and for repair purposes.

Forgings weighing up to several kilograms are forged by hand or on compressor hammers. Free forging of medium forgings is performed on steam and air hammers. Free-forging heavy forgings are made on hydraulic presses [9].

3. Free range shoeing TR

In 1978–1982, the Institute of Plastic Processing in Poznań developed a new method of crankshaft forging – Method TR (from the name of the inventor Tadeusz Rut). This method combines two processes that were previously separate and consists of simultaneous shaping of the metal vertically and horizontally using a special press. The TR method combines two previously separate processes: metal swelling and bending at the same time. The shaping of the finished product (crankshaft) takes place in one process, saving energy and time [4, 5].

Among the advantages of the TR method are [15]:

- high quality of products (correct course of fibres),
- material saving,
- possibility of forging large crankshafts on presses of relatively low pressure,
- reduction of labour intensity.

4. Objective of the survey

The aim of the study is to diagnose the crankshaft freely forged with the TR method in the range of strength correctness tested during the static tensile test and to test the impact strength by Chary method. The tests shall be carried out at ambient temperature.

The tests of the crankshaft will be carried out in a specialized factory laboratory of forging plant Stalowa Wola.

5. Subject of the study

The subject of the study was a crankshaft forged freely by the TR method. The product was made of stainless incandescent chromium steel with the addition of molybdenum (designation: X22CrMoV12-1; 1. 4923) according to EN 10269.

The crankshaft is an element of the piston-crankshaft system. A crankshaft is a mechanical part able to perform a conversion between reciprocating motion and rotational motion.

The crankshaft inspection model is shown in Fig. 2 and is manufactured in one of the factories in southern Poland.

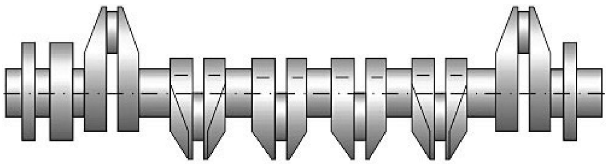

Fig. 2. Diagram of test crankshaft [16].

6. Alloy characteristics X22CrMoV12-1

The alloy of the crankshaft being analysed is a stainless steel chromium-plated alloy with the addition of molybdenum. This type of steel is used in the structural parts of steam turbines as well as in heavy-duty bolts. X22CrMoV12-1 steel achieves an increase in temporary strength thanks to the addition of vanadium [17].

Due to the relatively low chromium content of the alloy, corrosion resistance is limited under natural conditions. X22CrMoV12-1 is a steam resistant species. The chemical composition of X22CrMoV12-1 steel is shown in Table 1.

Table 1. Chemical composition of X22CrMoV12-1 steel [6].

Element	min [%]	max [%]
C	0.18	0.24
Si	–	0.50
Mn	–	0.90
P	–	0.025
S	–	0.015
Cr	11.0	12.5
Mo	0.80	1.20
Ni	0.3	0.8
V	0.25	0.35

The analyzed steel is characterized by excellent heat resistance, which is why it is successfully used in working with high temperatures reaching up to 600 degrees Celsius. X22CrMoV12-1 belongs to the group of weldable steels, which gives it an additional industrial character and significantly increases its scope of application. This is also due to the fact that this type of steel has a high degree of resistance to fatigue stress [17].

Physical properties of X22CrMoV12-1 steel:
- Density: 7.7 [kg/dm^3],
- Modulus of elasticity: 200 [GPa],
- Heat conduction coefficient 27 [W/(m × K)],
- Specific heat: 460 [J/(kg × K)],
- Appropriate resistance: 0,6 [Ω × mm^2)/m].

Physical properties such as density, modulus of elasticity and specific heat determined at temperature 20°C.

The mechanical properties of X22CrMoV12-1 are shown in Table 2.

Table 2. Mechanical properties of X22CrMoV12-1 steel [6].

Mechanical properties	parameter
Yield strengthRe (Rp0.2)	min. 600 [MPa]
Strength tensile (Rm)	800–950 [MPa]
Elongation at break(A5)	min. 14%
Hardness (HB)	max. 270 HB

7. Test methodology

HSW – Smithy Stalowa Wola has a specialized quality control laboratory. The tests are aimed at checking whether the activities performed during the production process meet the standards and expectations of customers.

The strength properties of the crankshaft were diagnosed on the Zwick 250 testing machine (Fig. 3). The range of tests included a static tensile test conducted at ambient temperature.

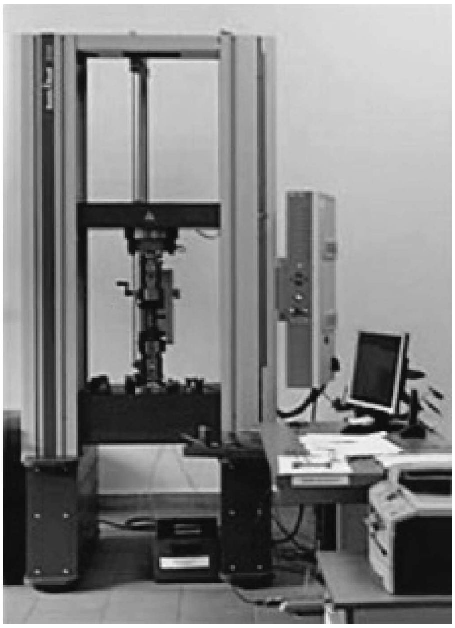

Fig. 3. Strength test machine – Zwick 250 [16].

Static tensile testing is one of the fundamental methods for testing the mechanical properties of materials used in technology. During the test, the dependence of the tensile force on the increase in the specimen length is recorded. At the end of the test, the strength properties shall be determined. In accordance with the scope of application of the PN-EN 10002-1 standard, the following values will be determined on the basis of the results recorded during the test:
- original diameter of the sample – d_0,
- area of the original cross-section of the sample – S0,
- linear deformability module (Young's modulus) – E,
- apparent yield strength at disproportionate prolongation- Rp,
- tensile strength – Rm,
- percentage elongation at break – As,
- percentage narrowing – Z.

In addition, crankshaft diagnostics will also include dynamic impact testing – the material's resistance to cracking under dynamic loading. This test makes it possible to determine the mechanical properties of the material which cannot be detected by static testing.

The impact test is particularly important for the steel being tested, which has been improved in terms of its physical properties, as the hardness and strength increase will result in a harmful increase in the brittleness of the material.

The test was carried out with a Zwick RKP 450 impact hammer (Fig. 4). The scope of the study included a Chary impact test at ambient temperature. In accordance with the scope of application of the PN-EN 10045-1 standard, the determination of impact strength – energy consumed for fracture of a specimen expressed in [J] with a standard test with a V notch was performed.

Fig. 4. Impact test machine – Zwick RKP 450 [16].

8. Results of tests

The 720, 175 × 80 size specimens used in the tensile test were taken crosswise from the thermally improved product. The results of the crankshaft tensile test are shown in Table 3.

Table 3. Crankshaft tensile test parameters obtained [16].

Requirements	d_0 [mm]	S_0 [mm^2]	E [GPa]	$R_{p0,2}$ [MPa]	Rm [MPa]	A_5 [%]	Z [%]
				≥ 700	900–1050	≥ 11	≥ 35
Result	9.99	78.38	186	943	1225	10.4	56

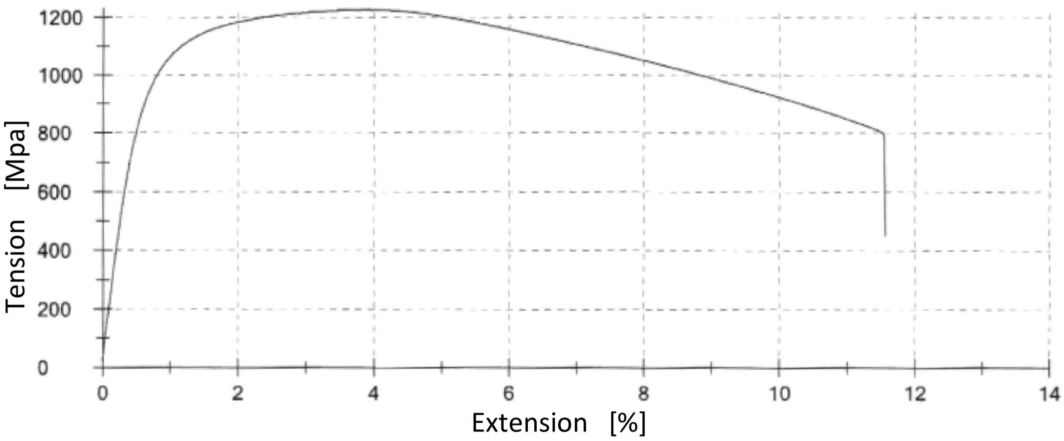

Fig. 5. Chart of steel specimen X22CrMoV12-1 [16].

In the tensile test the initial force was 20 MPa, the velocity of the E-module was 45 MPa/s and the velocity of the test was 0.008 1/s.

As shown in Table 3, the tensile test results show that not all of the resulting is within the specified standard. The coefficient of tensile strength (Rm) was 1225 megapascal i.e. 175 megapascal higher than the standard. The As parameter for the percentage elongation at break is 0.6 per cent below the reference period of the standard.

The tensile test procedure is best illustrated by the tensile diagram (Fig. 5) obtained from the testing machine. The shape of the graph obtained in the study depends on the type and condition of the tested material.

The crankshaft material does not have a clear yield point and there is no material flow. In order to find out the results of the tensile test from the cross-section of the tested specimen, a system of coordinates was applied which illustrates the relation between the stress and the accompanying elongation of the product specimen..

The results of the impact test are presented in Table 4. 3 V-Notch specimens were checked in this test. During the impact test the nominal stored energy was 300 J and the impact velocity was 5.234 m/s. The test was carried out at an ambient temperature of 20°C.

Table 4. Parameters obtained from the impact test [16].

Requirements	Width [mm]	Height to bottom of notch [mm]	S [mm^2]	Impact resistance (work) [J]
	10	8	80.00	≥ 20
1	10	8	80.00	12
2	10	8	80.00	12
3	10	8	80.00	12

As shown in Table 4, the width and height of each sample shall be the same as the width and height of the notch and the area of original cross-section of the sample. The value of the impact (operating) parameter in each of the three specimens reached too low a value – 12 J.

9. Additional tests

During the assessment of the results of the tests carried out in accordance with the requirements of the binding standard, it is probable that the results obtained by the ordering party and the contractor will differ from each other. In the case of strength tests, the tests shall be repeated on twice the number of specimens. The generation of incorrect results in repeated tests on one sample makes it necessary to carry out a heat treatment and a new test. The result of these trials shall be considered as definitive. If the result is inconsistent, the forging shall be disqualified [3].

In the case of disputable results, other additional tests may be performed, e.g. forging structure, chemical composition or non-destructive tests, e.g. penetration tests, ultrasonic tests or eddy current tests. If the self-tensioning of the forgings still does not meet the requirements, the product shall be disqualified.

10. Summary

The crankshaft is a component of the crankshaft piston system whose function is to convert the reciprocating motion into a rotary motion. The crankshaft is subject to bending, compressive, shearing, torsional and tensile forces. In addition, the member is loaded with stresses resulting from elastic deformations due to vibrations. For this reason, product quality tests are extremely important and are aimed at failure-free and safe operation.

In this paper, the validity and significance of crankshaft control tests, such as static strength tests and dynamic impact tests, was demonstrated.

The strength test revealed a significant exceeding of the required tensile strength parameter, the value of 1225 megapascal was reached. In addition, by using a product strength test, a non-conformity was detected

– insufficient percentage elongation after failure of the specimen.

The dynamic impact test showed that the sample did not meet the customer's requirements. The achieved impact strength value was 12 J with the requirement of values higher than or equal to 20 J.

The results obtained make it necessary to reheat and retest the product.

References

[1] Babica M., Pająk E., *Concept of the method of elimination of inconsistencies in production processes*, Scientific Notebooks of the Rzeszów University of Technology, Machine Construction and Production Management, Publishing Office of the Rzeszów University of Technology, Rzeszów, 2006.

[2] Czerwińska K., Pacana A., *Application eddy currents in the control quality piston Diesel*, International Journal Of Interdisciplinarity In Theory And Practice, Wydawnictwo ITPB, http://www.itpb.eu/, ITPB 11/2016.

[3] Rehmus-Forc A., *Problems of acceptance tests of forgings for shafts of steam turbines*, Technical journal Mechanics, notebook 6, 2009.

[4] Rut T., Walczyk W., *Development of forging in press tools and equipment – Method TR.* Matt. Conf. MANUFACTURING'01 Contemporary Manufacturing Problem, Poznań, Vol. 1, 8–9 November 2001.

[5] Rut T., Walczyk W., *Development of forging in press tools*, Method TR. Matt. Conf. Interior: Interior Conf. Science and Technology "Construction and technology of extrusions and mouldings", Poznań-Wąsowo, 14–16 June 2004.

[6] Materials unpublished Smithy Stalowa Wola, Stalowa Wola, 2017.

[7] Sęp J., Pacana A., *Methods and tools of quality improvement*, Vol. 3 in the series *Design and implementation of quality systems*, Vol. 3, OWPRz, Rzeszów, 2001.

[8] Siemiątkowski Z., *Selected issues of production of crankshaft monolithic forgings for marine engines and generators*, [in:] Logistics, Institute of Logistics and Warehousing, no. 6, 2010.

[9] Sińczak J., *Basics of plastic processing processes*, AKAPIT Scientific Publishing House, Kraków, 2010.

[10] Sińczak J., Łukaszek A., *Tool load with multiple forging of the roller bearing rings*, Plastic Working of Metals, 12, 2001.

[11] Urbaniak M., *Quality management. Theory and practice*, Difin, Warsaw, 2004.

[12] Walenty J., *Manufacturing techniques – materials for students*, West Pomeranian University of Technology in Szczecin, Szczecin, 2010.

[13] Wolniak R., Skotnicka-Zasadzień B., *Quality management for engineers*, Publishing House of the Silesian University of Technology, Gliwice, 2010.

[14] www.stalnierdzewna.com [readout 06.05.2018].

[15] www.metale.org [readout 06.05.2018].

[16] www.hsw-kuznia.pl/ [readout 06.05.2018].

[17] www.stalespecjalne.com.pl [readout 06.05.2018].