

Analysis of Metallic Materials used for Manufacturing of Extruders Screws

Anna Dziubińska ^{1,*}, Janusz Sikora ²

¹ Department of Computer Modelling and Metal Forming Technologies, Lublin University of Technology, Faculty of Mechanical Engineering, Nadbystrzycka 36 Str., 20-618 Lublin, Poland

² Department of Polymer Processing, Lublin University of Technology, Faculty of Mechanical Engineering, Nadbystrzycka 36 Str., 20-618 Lublin, Poland

Abstract: The article presents a review of metallic materials used for manufacturing of extruders screws. The analysis is carried out for the NEWEX project, which aims to develop and test an innovative extruder [1-2]. The collected knowledge about the materials used to date to produce screws of extrusion machines and methods of increasing their service life will allow to design a new extruder consisting of materials of the highest quality and durability. Currently the screws are usually manufactured from steels for nitriding, heat resisting steels, tool steels and stainless steels. The study provides an analysis of the chemical composition and mechanical properties of the most commonly used material types. Among those, the following types of steels for nitriding, in accordance with the standard PN-EN 10085:2003 can be distinguished: 34CrAlNi7-10, 34CrAlMo5-10, 31CrMoV9. The type of heat resisting steel used for screws of extrusion machines is 14CrMoV6-9 according to the standard PN-H-84024:1975 (withdrawn without replacement). The most commonly used tool steels are X37CrMoV5-1 and X153CrMoV12 according to the standard PN-EN ISO 4957:2018-09. Among the stainless steels of the standard PN-EN 10088-1:2014-12 the steels X90CrMoV18 and X39CrMo17-1 are used in the production of screws. The study also presents methods of increasing the durability and strength of the screws of extrusion machines, including surface treatment processes. These processes include: hardening, surfacing and coating, as well as thermochemical treatment in the form of: carburising, nitriding and sintering.

Keywords: *metallic materials for screws of extruders, steels for nitriding, heat resisting steels, tool steels, stainless steels, surface treatment*

1. Characteristics of the materials used in the manufacture of extruders screws

Materials used in the production of screws of extrusion machines are characterised by high strength, hardness and long life. This is important because of the high mechanical loads that occur during the operation of extruders. In particular, during the extruder start-up, the loads may exceed the value of 60-80 MPa, while at the screw core the loads for torsional stresses reach maximum values [3]. Materials for screws of extrusion machines are also characterised by high resistance to abrasion and corrosion. As a result, they are not prone to the formation of adhesive bonds between the screw coil ridges and the internal surface of the barrel. The most commonly used metallic materials for the production of screws of extrusion machines can be distinguished:

- ✓ *steels for nitriding according to the PN-EN 10085:2003 standard, such as: 34CrAlNi7-10 (1.8550), 34CrAlMo5-10 (1.8507), 31CrMoV9 (1.8519) [4];*
- ✓ *steel for operation at elevated temperatures in accordance with the PN-H-84024:1975 standard, e.g. 14CrMoV6-9 (1.7735) [5];*

* Corresponding author: Anna Dziubińska, E-mail address: a.dziubinska@pollub.pl

Received: 2019.05.21
Revised: 2019.06.05
Accepted: 2019.08.27
Available online: 2019.09.15

✓ tool steels according to PN-EN ISO 4957:2018-09, e.g. X153CrMoV12 (1.2379), X37CrMoV5-1 (1.2343) [6];

✓ stainless steels according to standard PN-EN 10088-1:2014-12 in grades such as X90CrMoV18 (1.4112) and X39CrMo17-1 (1.4122) [7];

✓ nickel-based materials (e.g. Inconel nickel alloys, Hastelloy).

Nitriding steels are steels designed for surface hardening by saturating the surface of the finished product with nitrogen. Steels used for nitriding are those whose main components are aluminium and chromium, as well as molybdenum, titanium and vanadium, which form very hard nitrides with nitrogen. Medium carbon steels with a carbon content of 0.25-0.45% are nitrided. These steels, thanks to appropriately selected content of alloying additives such as chromium, molybdenum and first of all aluminium, allow to obtain the highest hardness of the surface layer after nitriding. The hardness of the surface layer after nitriding does not decrease after heating to temperatures up to 500°C and remains at a constant level also during heating to this temperature. The main factor determining the hardness of the nitrided layer is a properly selected chemical composition. The depth of cure in practice depends only on the time of nitriding, which usually ranges from 24 to 72 hours. Other factors, such as temperature (500°C) and the nitriding medium, are unchanged and do not have a major impact on the properties of the hardened layer. Tables 1-2 show the chemical composition and properties of the exemplary nitriding steel grade 34CrAlMo5-10 (1.8507) used for the production of screws of extrusion machines. Other grades of analysed steels used for screw production include 34CrAlNi7-10 and 31CrMoV9.

High-temperature steels are a group of steels popularly known as boiler steels, which can be used at temperatures below 600°C. Their main applications are machine parts and equipment used in the power industry such as: boiler and turbine fittings, pressure tanks for the chemical industry, power, steam and gas water turbines, elements of plasticising system, extruders for plastics such as screw or barrel and other products that require resistance to higher temperatures. Among steels for working at elevated temperatures according to the PN-H-84024:1975 standard, the of screws of

Table 2: Mechanical properties of steel 34CrAlMo5-10 in quenched and tempered condition.

Rm [MPa]	Re [MPa] min.	A [%]	KV [J]	Hardness of nitrided surface HV1
800-1000	600	14	35	950

Table 3: Conditions for heat treatment of steel 34CrAlMo5-10.

Soft annealing T [°C]	Hardening		Tempering T [°C]	Nitriding T [°C]
	T [°C]	Environment		
650-750	870-930	Oil or water	580-700	480-570

Table 4: Chemical composition of steel 14CrMoV6-9 (% by weight).

C	Si max.	Mn	P max.	S max.	Cr	Mo	V
0.11-0.17	0.25	0.8-1	0.02	0.015	1.25-1.5	0.8-1	0.2-0.3

Table 5: Mechanical properties of steel 14CrMoV6-9.

Rm [MPa]	Re [MPa] min.	A [%]	KV [J]	Surface hardness HV
1000-1300	850	10	40	800

Table 6: Conditions for heat treatment of steel 14CrMoV6-9.

Soft annealing T [°C]	Hardening	
	T [°C]	Environment
730-780	940-980	Oil or water

Table 7: Chemical composition of steel X37CrMoV5-1 (% by weight).

C	Si max.	Mn	Cr	Mo	V
0.33-0.41	0.8-1.2	0.25-0.5	4.8-5.5	1.1-1.5	0.3-0.5

extrusion machines are equipped with a grade like 14CrMoV6-9, whose chemical composition and properties are shown in Tables 4-6. The basic alloying additives of these steels are chromium, which increases resistance to oxidation, and molybdenum, whose presence increases the creep resistance of steel.

Alloyed tool steels for hot work are used to produce tools that process material heated to high

Table 1: Chemical composition of steel 34CrAlMo5-10 (% by weight).

C	Si max.	Mn	P max.	S max.	Al	Cr	Mo	Ni	V
0.3-0.37	0.4	0.4-0.7	0.025	0.035	0.8-1.2	1.0-1.3	0.15-0.25	-	-

Table 8: Conditions for heat treatment and properties of steel X37CrMoV5-1.

Soft annealing T [°C]	Hardening		Tempering T [°C]	Nitriding T [°C]	Hardness HRC min.
	T [°C]	Environment			
780-820	1020	Oil	550	470-550	48

temperature (in order to reduce its deformation resistance). They are used to manufacture plasticising system elements, forging tools and pressurised casting moulds. These steels are characterised by high strength and hardness at higher operating temperatures, relatively low susceptibility to thermal fatigue, high resistance to abrasion and destruction by the treated material. Tool surfaces made of alloyed tool steels for hot work, which are exposed to abrasion during operation, can be padded, with padding capable of being used both for the production of new tools and for the regeneration of worn-out ones. The most commonly used grades in the production of extruder screws for plastics include such steels according to standard PN-EN ISO 4957:2018-09 as X153CrMoV12 and X37CrMoV5-1 (Table 7-8).

Stainless steels are a group of high alloy steels resistant to corrosion, characterised by significant resistance to atmospheric, water and earth corrosion. The main alloying addition in stainless steels is chromium, which (depending on the grade) occurs in amounts ranging from 12% to 19%. Greater corrosion resistance of steel can be obtained by increasing its electrochemical potential by introducing a metal with a higher electrochemical potential (in this case chromium at least 13-14%) or the formation of oxides on the surface of steel (passivation of steel) by the addition of chromium, aluminium or silicon. In Tables 9-13 stainless steels in grades X39CrMo17-1 and X90CrMoV18 are characterised. They are commonly used for the production of plasticising elements of extruders such as screws and barrels.

Table 9: Chemical composition of steel 14CrMoV6-9 (% by weight).

C	Si max.	Mn	P	S	Cr	Mo	Ni
0.33-0.45	1	1.5	0.04	0.015	15.5-17.5	0.8-1.3	1

Table 10: Mechanical properties of steel X39CrMo17-1.

Rm [MPa]	Re [MPa] min.	A [%]	Hardness in HRC improved condition min.
750-950	550	12	28

Table 11: Conditions for heat treatment of steel X39CrMo17-1.

Soft annealing T [°C]	Hardening		Tempering T [°C]
	T [°C]	Environment	
750-850	980-1060	Oil	650-750

Table 12: Chemical composition of steel X90CrMoV18 (% by weight).

C	Si max.	Mn	P	S	Cr	Mo	V
0.85-0.95	1	1	0.04	0.015	17-19	0.9-1.3	0.07-0.12

Table 13: Conditions for heat treatment and properties of steel X90CrMoV18.

Soft annealing T [°C]	Hardening		Tempering T [°C]	Hardness after HRC hardening and tempering min.
	T [°C]	Environment		
780-840	1000-1080	Oil or air	100-200	55-57

Among the nickel-based materials used in the production of extruder screws, one can distinguish Inconel and Hastelloy alloys. Inconel is an alloy of nickel, chromium and iron. It is very resistant to corrosion and can be used at high temperatures of 1100 °C. It is characterised by good mechanical properties – high strength, formability. Whereas Hastelloy is a 50-55% nickel alloy with 9% chromium and 17-21% molybdenum, containing tungsten, silicon and cobalt as alloying additives up to 1% and iron as the rest. This alloy is characterised by high heat resistance, significant resistance to corrosion and, in some varieties, high heat resistance.

2. Ways to increase the durability and strength of extruder screws

Among ways to increase the durability and strength of the top layers of the backs of extruder coils

are surface treatment processes. They may include:

- ✓ *heat treatment, among others, such methods as: surface hardening, surfacing,*
- ✓ *thermal-chemical treatment, including technologies such as nitriding and carburising.*

Surface hardening consists in quick heating of the top layer of the screws to the hardening temperature of steel and then quick cooling. Surface hardening makes it possible to limit heating to a thin surface layer only in places which should be heat-treated. Therefore, it does not cause high stresses and thermal deformations. Depending on the method of heating, inductive, flame, bathing, contact and electrolytic can be distinguished. In the case of surface hardening of extruder screws, induction hardening is most often used, which consists in heating the produced screws with the use of current induced by an alternating magnetic field.

It is used to coat the working surfaces of the screws, especially in the area of coils, with metal alloys resistant to abrasion and corrosion. They are applied by electric, plasma or spray welding. The most common materials used are those containing components: iron, cobalt, nickel, copper, chromium, titanium. The thickness of the welded layer after treatment is min. 1 mm. (Fig. 1a) The proportion of alloying elements can be up to 20%. Cobalt and nickel alloys are used in the processing of polymeric materials with increased corrosion aggressiveness, while the hardest surfaces are obtained from tungsten carbides (Fig. 1b).

The extruder screws are made with special properties, e.g. a coating made of chromium nitride (CrN) or titanium nitride (TiN), which has the best release properties, or they are also made of bimetallic alloys in order to achieve perfect cooperation of the whole plasticising system. The figure shows three screws that worked for 2000 man-hours in PMMA (polymethyl methacrylate) processing. The screw with CrN chromium nitride coating is shown in Fig. 2a. It has no accumulation of material and can continue to be used without any additional material. The TiN coated screw (Fig. 2b) is completely free of any deposits and has practically no signs of use. The screw of the extruder without the coating (Fig. 2c)

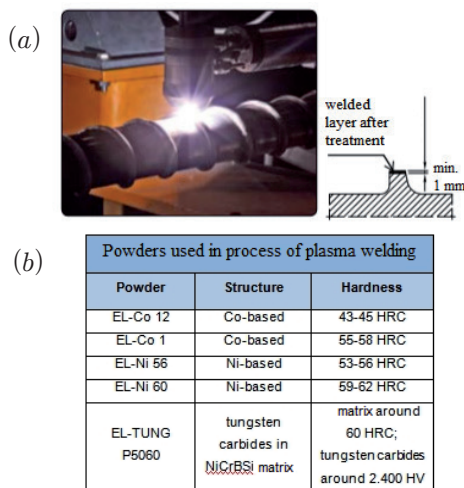


Fig. 1: Plasma welding of the working surfaces of extruder screws.

has residues of the processed material that need to be removed and a black deposit that needs to be polished so that it does not leave streaks.

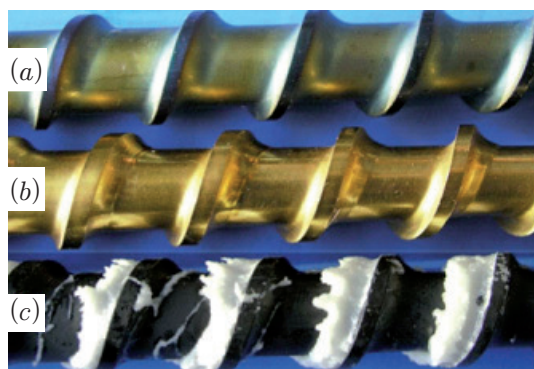


Fig. 2: Extruder screws: (a) with CrN coating, (b) with TiN coating, (c) without coating [8].

Plasma powder coating technology is mainly used to provide extruder screws with high resistance to abrasive wear, corrosion and temperature. This technology allows the maximum functionality of the plasticising systems to be maintained over a long period of time. Plasma surfacing technology is used because of its advantages over other welding methods. The most important benefits are: a high quality, defect-free weld pad that provides optimum wear resistance; low blending with the parent material; high process efficiency; constant hardness on the welded surface. The spray coating technology is mainly used for the production of new coated screws on the entire winding surface,

but less for regeneration. In order to improve the working surface, the worm made of alloy steel for improvement, with weld padded coils, can be additionally nitrided or coated with technical chrome with a thickness of 15-20 micrometres.

Nitriding of extruder screws consists in diffusion impregnation of the top layer of the material with nitrogen. Nitrides formed in the diffusion layer increase the hardness of the material and its resistance to wear. The temperature at which the material is saturated ranges from 480 to 600°C. In the case where the treated material has been tempered, the maximum temperature of the process must be at least 20÷30°C lower than the minimum temperature of earlier tempering. Surfaces of worms are nitrided to a depth of up to 0.6 mm and the hardness of the surface after nitriding is min. 900 HV.

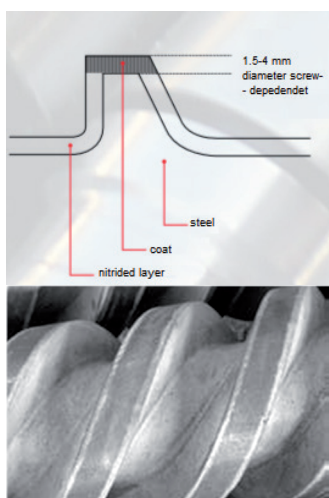


Fig. 3: Nitriding of extruder screws.

Carburising is another method used to increase hardness and abrasion resistance of extruder screw surfaces. It is a thermal-chemical treatment consisting in diffusive saturation of the surface layer of steel with carbon during the heating of the work piece within a specified period of time in the medium in which the atomic carbon is produced.

3. Conclusions

The paper presents the current state of knowledge in the field of materials used for the production of extruder screws and methods of increasing their service life. The analysis of the problem was carried out on the basis of specialist literature and available standards as well as trade offers of extruder

producers. On the basis of the review it was stated that there are few scientific studies that would address the subject of recommended materials for particular parts of plasticising systems and methods used in industry to increase their service life. The present study systematises the available knowledge in this area. The information collected will be used for the purposes of the international project "Investigation and development of a new generation of machines for the processing of composite and nanocomposite materials" realised within Horizon 2020, which assumes designing and manufacturing a modern extruder from highest quality materials. An important element of the designed innovative extruder will be a special construction and execution of the screw, as well as a new active grooved feeding zone, the original rotating cylinder segment. The introduction of new concepts for important elements of an extruder made of the best materials will ensure the extruding of the final product with improved properties and will allow the processing of materials that could not be extruded so far, as well as food, cosmetics and pharmaceuticals.

Acknowledgments

The project leading to these results has received funding from the European Union, Horizon 2020 research and innovation programme under Marie Skłodowska-Curie grant agreement no. 734205, Project symbol H2020-MSCA-RISE-2016-GA734205; "Investigation and development of a new generation of machines for the processing of composite and nanocomposite materials" - project acronym NEWEX, Fund of the project: 1.260.000 Euro; Duration of the project: 2017 – 2020.



References and Notes

- [1] Sikora J.W. (2017). Newex project – research issues and other activities. International Scientific Conference "Pro-Tech-Ma 2017 – Surface Engineering 2017", 20-23 June 2017, Bardejov, Slovakia, pp. 86.
- [2] Dulebová Ľ. (2016). H2020 – NEWEX project na Strojnickej fakulte. Halo TU, no. 4, pp. 31.
- [3] Stasiak J. (2008). Materials used for manufacturing of cylinders and extruder screws. Polymer Processing, vol. 14, no. 2, pp. 36-38.
- [4] PN-EN 10085:2003 standard. Steels for nitriding. Polish Committee for Standardization. Warsaw.

- [5] PN-H-84024:1975 standard. Steel for operation at elevated temperatures. Polish Committee for Standardization. Warsaw.
- [6] PN-EN ISO 4957:2018-09 standard. Tool steels. Polish Committee for Standardization. Warsaw.
- [7] PN-EN 10088-1:2014-12 standard. Stainless steels. Polish Committee for Standardization. Warsaw.
- [8] TRANS-WEST. <http://www.transwest.pl/pl,67,slimaki--cylindry--uklady-plastyfikujace.html>

