Combined Rolling and Extrusion production of Wire Rod

Alexander Salnikov[1], Alexander Krokhin[2], Alexander Alabin[3] and Martijn Vos[4]
1. Department Head
RUSAL, ETC, Krasnoyarsk, Russian Federation
2. Head of Department Casting and New Product Development
3. Head of Unit
4. Director of New Product Commercialization
RUSAL, Moscow, Russian Federation
Corresponding author: martijn.vos@rusal.com
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Abstract

The Combined Rolling and Extrusion process (CRE) is an energy efficient production method of wire rod. It combines rolling and extrusion of a continuous cast bar into one single process step. Further reduction and calibration occur in only four subsequent rolling sections. The CRE equipment is designed to produce 1xxx, 3xxx, 4xxx, 5xxx, 6xxx and 8xxx series alloys. The work hardening of the 5xxx series alloys determine the design requirements for the rolling torque as well as the extrusion conditions. Process simulation of the alloys AlMg5, 5356 and 5019 were used during the design and engineering of the equipment.

Keywords: Wire Rod, Continuous casting, Combined Rolling and Extrusion process (CRE), Welding wire.

1. Introduction

RUSAL and the Siberian Federal University in Krasnoyarsk share a long history. Many employees in Siberian smelters have been educated there, and both partners are involved in numerous joint research projects.

The CRE process was developed at the University in the Laboratory of Metal Forming. This faculty specializes in pioneering new technologies and processes for press-products from non-ferrous metals and alloys. The purpose of the invention was to find an efficient process for the production of wire rod and small sections, with low CAPEX and OPEX and a small industrial footprint.

RUSAL took the decision a few years ago to industrialize the process and found the SMS Group in Germany to build the first industrial pilot line. The CRE line was commissioned in Casthouse 1 of RUSAL's Irkutsk smelter and is used for production of wire rod as well as experimental trial production.

2. Process Comparison

The standard process used around the world for the production of wire rod is Continuous Casting & Rolling (CCR). In this process, a continuous cast bar is deformed by a sequence of rolling steps, normally 8 to 10, into a standard 9.5 mm diameter wire rod, which is coiled at the end of the line. CCR is characterized by a single flow metal scheme (Figure 1).

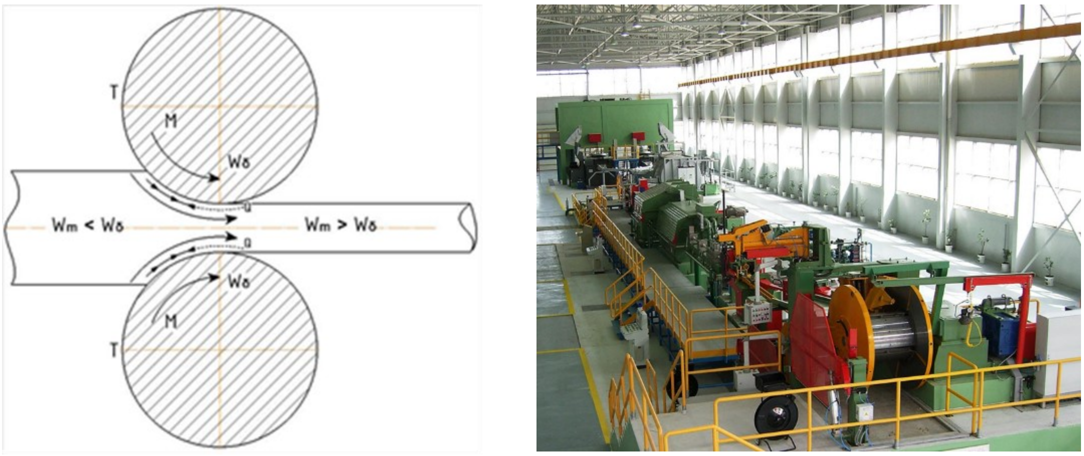

Figure 1. Left: Single flow scheme, Right: CCR line.

The CRE process combines the rolling and extrusion into one single process step. An extrusion die in a die holder is positioned hydraulically directly behind the rolls. The metal flow is a double flow from extrusion in combination with active friction forces from the rolling process (Figure 2). The deformation rates are high and range from 5 to 20.

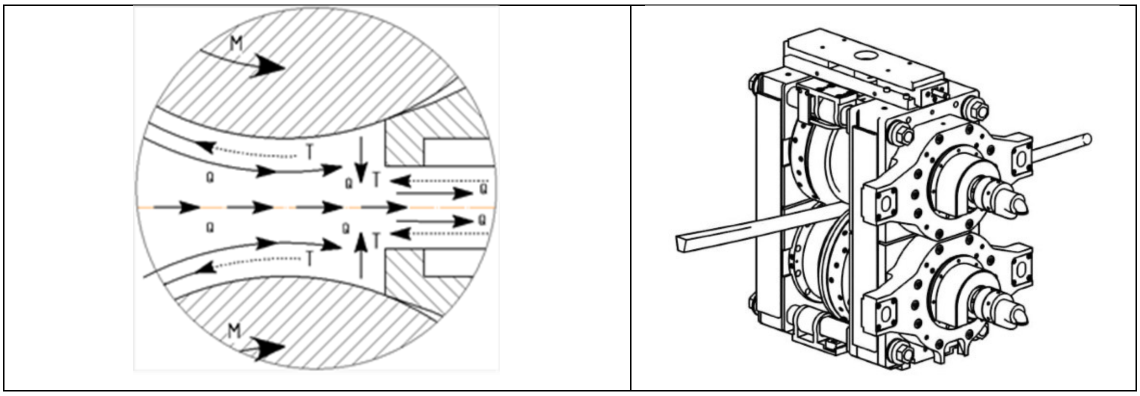

Figure 2. Left: Double flow scheme, Right: CCR line.

A continuous cast bar is rolled / extruded in a single process step to a 16 mm or 18 mm diameter rod. Subsequently only 4 rolling operations reduce the extruded rod to a 9.5 mm diameter wire rod, in two stages of reduction and calibration (Figure 3). CCR lines can produce up to 6 tonnes per hour, whereas the CRE line is limited to 3 t/h.

Figure 3. Reduction and calibration rolls of CRE line.

3. Process Benchmark

RUSAL has several CCR lines in operation and the internal process benchmark shows the advantage of CRE (in relative numbers):

- Foot print = approximately 60 %
- Maintenance costs = approximately 30 %
- CAPEX (Capital Expenditure) = approximately 60 %
- OPEX (Operation Expenses) = approximately 75 %.

AA1350 - H14 wire rod, is produced in both processes. A comparison of the mechanical properties is shown in Table 1. The results are based on 50 different production batches.

The resistivity of this alloy is 0,02787 μΩ·m, which corresponds to 62 % IACS (International Annealed Copper Standard). The mechanical properties are very similar. The ultimate strength is comparable in both processes; however, the elongation is slightly higher in CRE. This is due to smaller grain sizes caused by the high deformation rates of the CRE process.

Table 1. Mechanical property comparison of AA1350 – H14.

	CCS	**CRE**
	Min / Av / Max	Min / Av / Max
Ultimate tensile strength (UTS), [MPa]	108 / **119** / 127	112 / **117** / 119
Standard deviation	3.35	1.8
	Min / Av / Max	Min / Av / Max
Elongation [%]	7 / **11** / 15	12 / **14** / 16
Standard deviation	1.98	1.4

The CRE line is primarily used to produce conductor wire rod, as well as trial production of aluminium-silicon and aluminum-magnesium alloys for different development purposes. RUSAL plans to continue the industrialization of the process and the next generation CRE equipment is being engineered in the Russian Federation (Figure 4).

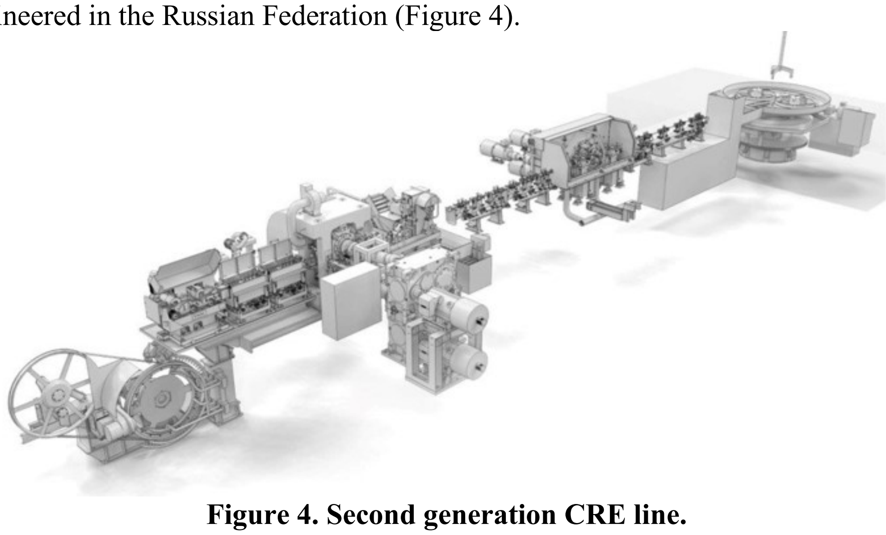

Figure 4. Second generation CRE line.

5. Modelling CRE Process for Alloy AlMg5

Three 5xxx series alloys AlMg3, 5356 and 5019 were used in process modelling during equipment engineering to determine temperatures as well as forces and torque on the rolls and the extrusion die [1].

The alloy 5356 is a commonly used welding wire and contains 5 % magnesium. AA5019 also contains 5 % magnesium but is predominantly used for mechanical applications such as rivets and screws. Table 2 shows the mechanical properties taken at different temperatures and deformation rates.

Table 2. Mechanical properties of AlMg3, AA5356 and AA5019.

T (℃)	Mechanical properties at different deformation rates								
	5 mm/min			10 mm/min			20 mm/min		
	σ_B (Mpa)	σ_T (Mpa)	δ (%)	σ_B (Mpa)	σ_T (Mpa)	δ (%)	σ_B (Mpa)	σ_T (Mpa)	δ (%)
Alloy AlMg3									
350	130	103	34.5	138	105	23.4	138	106	24.4
430	76	76	23.4	86	83	24.8	96	90	28,0
470	54	54	32.3	64	64	30.4	71	71	33.4
Alloy 5356									
350	133	102	37.2	148	106	17.8	150	108	14.2
430	85	80	38.6	86	82	23.9	87	84	21.8
470	46	45	57.6	47	46	57.7	63	62	54.8
Alloy 5019									
350	153	118	24.6	145	113	31.0	150	104	27.4
430	90	88	27.0	117	98	30.7	113	97	25.5
470	74	66	36.4	90	89	31.4	104	92	21.9

The Modelling input data and parameters are shown in Table 3.

Table 3. Input data.

Parameter	Value
Initial workpiece temperature, °C	430
Initial tool temperature, °C	20
Clearance between rolls, mm	20

Roll diameter, mm	604
Matrix mirror dimensions, mm	31 × 42
Roll speed, rpm	5.0 and 2.5
Cross-sectional area of cast workpiece, mm^2	1 232
Die belt height, mm	3
Drawing ratio for rod diameter 16 mm	6.5
Drawing ratio for rod diameter 18.4 mm	4.9
Maximum and minimum element size, mm	0.6–2.2
Integration method	explicit
Friction index according to Siebel's law	0.9

To analyze the shape change and metal flow in the CRE process, three characteristic zones are defined: rolling, spreading and extrusion. Figure 5 shows the metal flow. The model visualizes the capture of the bar by the rolls, the further deformation and filling of the cavity in front of the extrusion die, and finally the steady state extrusion process.

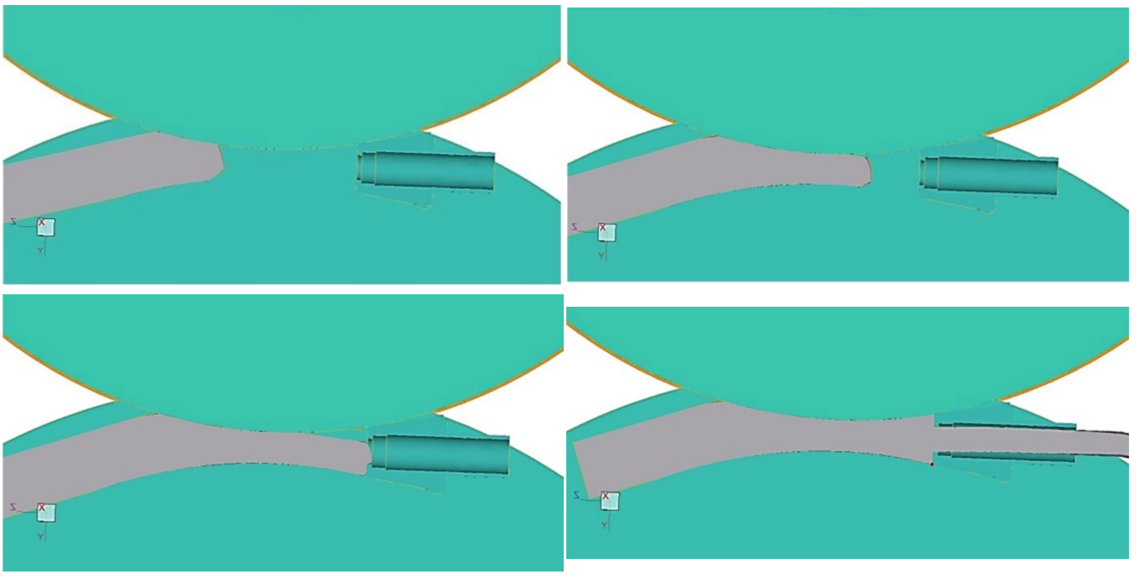

Figure 5. Grabbing, rolling, spreading and extrusion.

Figure 6 shows the finite element mesh on the left, and image on the right shows three characteristic points for temperature determination:

1 - At the contact point of the work piece and the roll with the ridge;
2 - In the center of the work piece;
3 - At the contact point of the work piece and the roll with the groove.

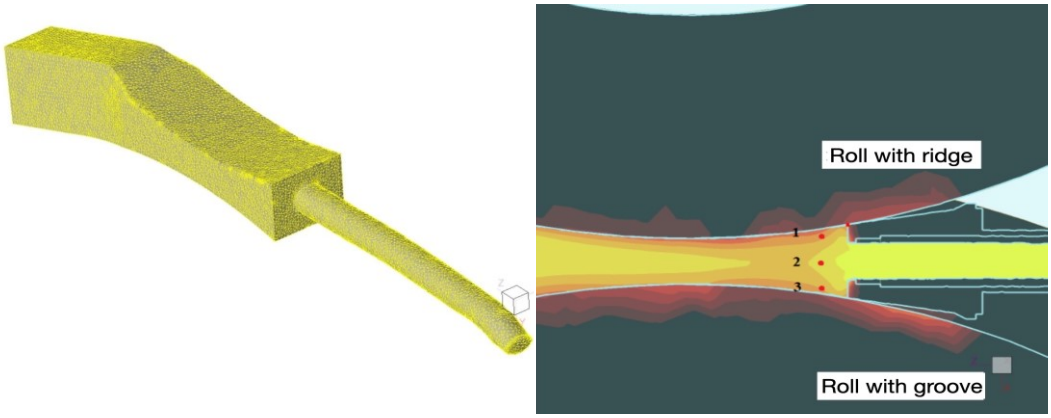

Figure 6. Left: Finite element mesh, Right: Temperature analysis.

The analysis shows that at the beginning of the rolling process, due to the cooling of metal on the rolls, the temperature of metal drops by about 20–30 °C. At the same time, the temperature on the roll with a groove is lower than in other parts of the bar, because the area of metal contact with the tool is larger. At the stage of distribution pressing the temperature drops, and then at the stage of pressing, when the metal is extruded at high speeds, it increases again to values of about 450–460 °C (Figure 7).

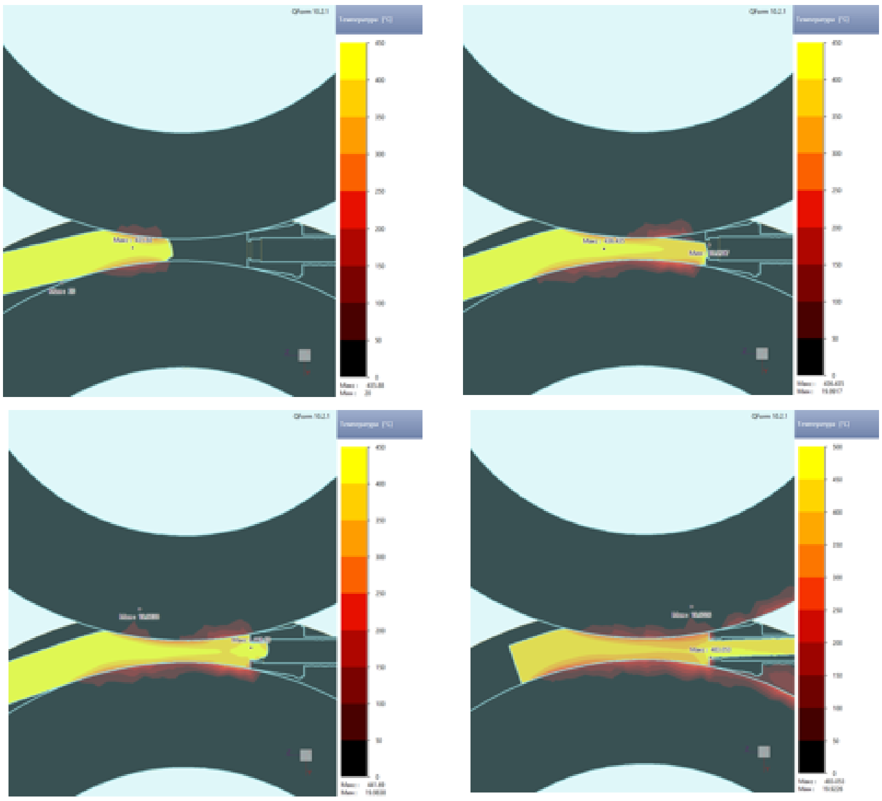

Figure 7. Temperature profile during different stages.

The calculated results of temperature change along the length of the deformation zone for AlMg3 is shown in the Figure 8.

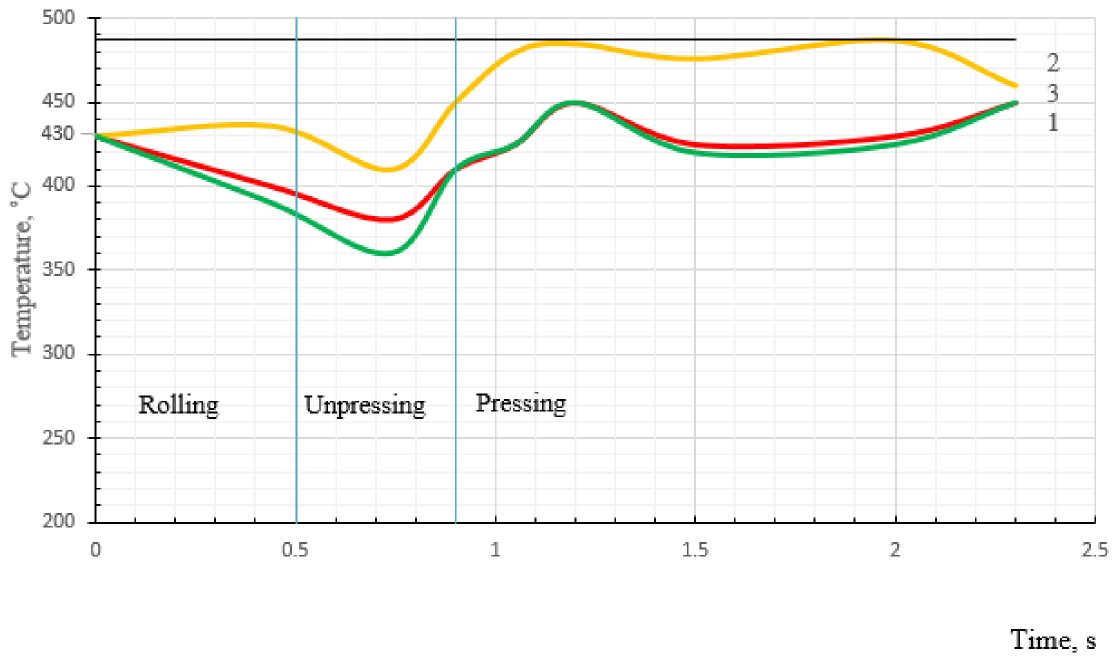

Figure 8. Temperature profile for AlMg3.

All three AlMg alloys show a very similar temperature profile. The modelling has helped to determine the optimal temperatures for the given geometric and technological parameters for the studied alloys:

- Cast bar temperature prior to rolling (430 ± 10) °C
- Initial tool temperature 20 °C
- Temperature at the extrusion die outlet (450 ± 10) °C.

6. Force and Torque Analysis

The analysis of the torque on the rolls and the forces on the extrusion die for AlMg3 is shown in Figures 9, 10 and 11.

The maximum force acting the on the rolls is 1 246 kN and the maximum force acting on the die is 534 kN. The torque on the rolls shows a similar pattern, however, the torque on the roll with the groove (line 1) is 2.7 times higher than the torque on the roll with the ridge.

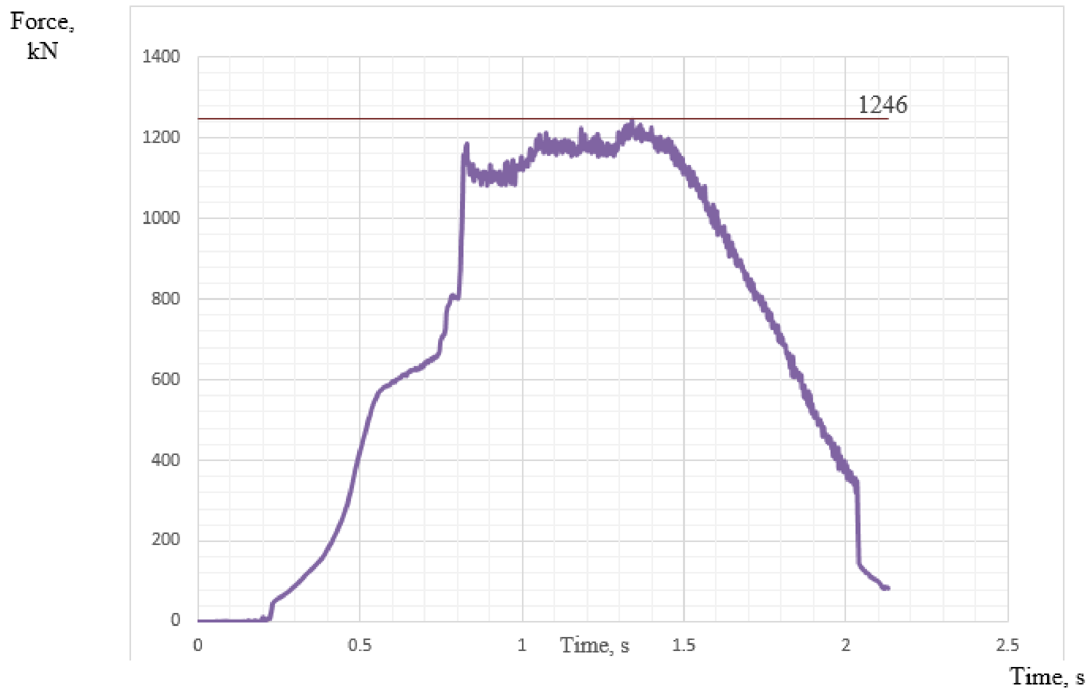

Figure 9. Force on the rolls for AlMg3.

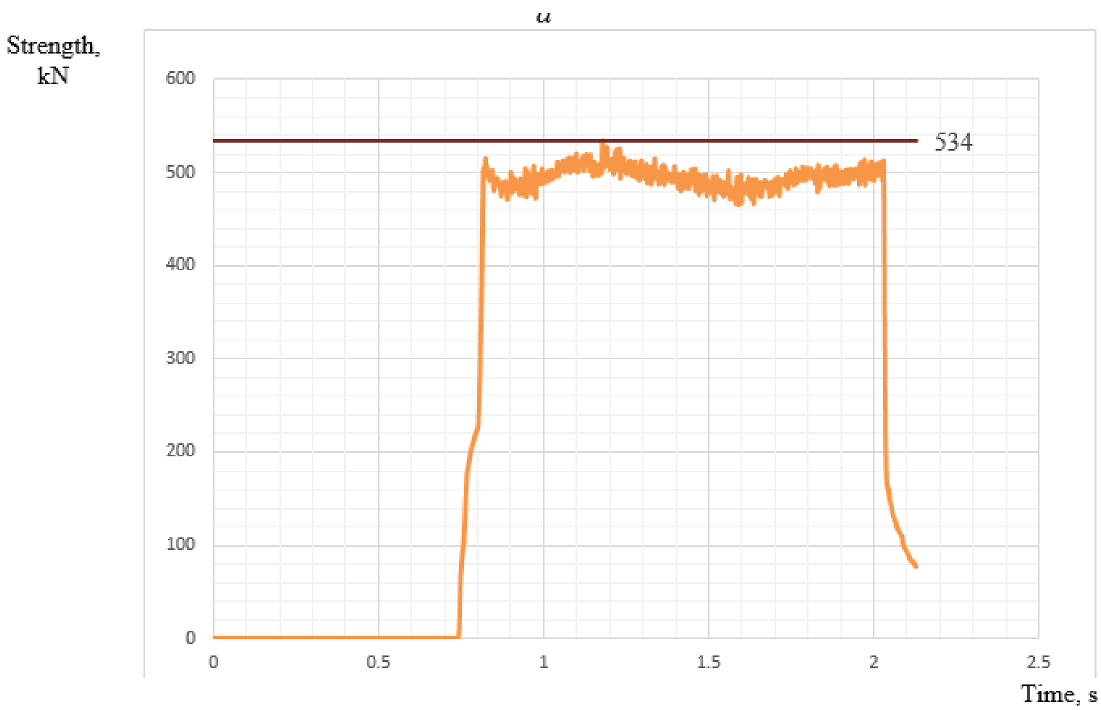

Figure 10. Force on the extrusion die for AlMg3.

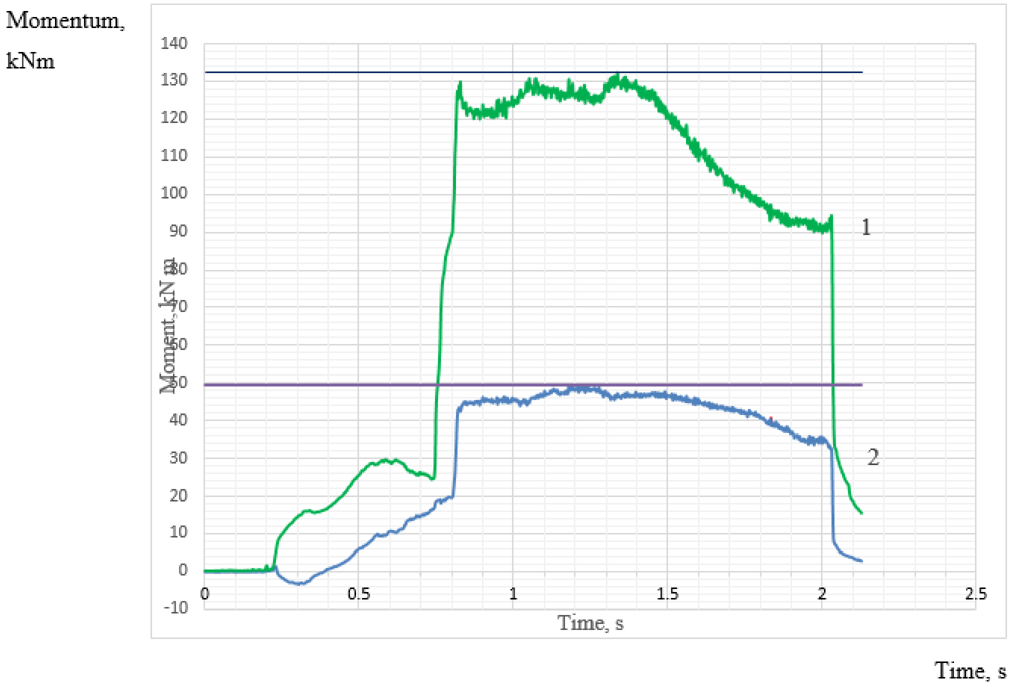

Figure 11. Torque on rolls for AlMg3.

values for the three alloys are shown in Table 4 with the higher values occurring for 5019.

Table 4. Force and torque analysis.

Drawing ratio	Force on rolls (kN)	Force on die (kN)	M1 (kN·m)	M2 (kN·m)
AlMg3				
4.9	1170	448	124	44
6.5	1246	534	132	50
AA5356				
4.9	1460	614	162	59
6.5	1622	713	176	64
AA5019				
4.9	1815	704	194	68
6.5	2108	808	224	77

7. Conclusions and Next Steps

CRE is a new conceptual forming process for the production of wire rod and thin sections. The pilot line at RUSAL Irkutsk is in operation producing conductor wire rod and experimental alloy production. Operational production costs are 25 % lower compared to conventional Continuous Cast Rolling. The 2nd generation CRE line is in planning.

Finite element modelling has been effectively used during the design and engineering of the process and equipment.

8. Reference

1. Denis S. Voroshilov, Sergey B. Sidelnikov et al., Simulation of combined rolling-extrusion process for round section billets in closed box caliber, *The International Journal of Advanced Manufacturing Technology,* (2023) 127, 2893–2910.