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EFFECT OF ROLL FORCE DECREASE IN HOT ROLLING OF DP600 STEEL GRADE BY USE OF ROLL GAP LUBRICATION

EFEKT SPADKU SIŁY WALCOWANIA NA GORĄCO STALI DP600 W WYNIKU SMAROWANIA KOTLINY WALCOWNICZEJ

Key words: hot rolling, dual phase steel, roll force, roll gap lubrication.

Abstract: The force required for plastic deformation of steel in the hot rolling process is an important parameter which impacts roll wear, strip steering in finishing stands, shape and profile of the rolled strip and energy consumption. Theoretically, the roll force could be effectively decreased by rolling strips with higher temperatures and a lower speed or by reducing the strip's input thickness. Due to the required mechanical properties of hot rolled strips as well as the continuous drive toward increased rolling line productivity and cost optimisation, in most cases, it is impossible to lower roll force by changing these two parameters. Roll gap lubrication effectively decreases the roll force, and lowering the friction between the work roll's surface and rolled material reduces roll force by 5% to 20%. Lower roll force brings obvious results in lower energy consumption, but even more important are benefits coming from lower work roll wear and improved strip shape and profile. These issues are particularly important during the hot rolling of dual-phase steel, which due to relatively low final rolling temperature (FRT), requires a higher roll force resulting from increased steel yield stress at lower temperatures.

Słowa kluczowe: walcowanie na gorąco, stale dwufazowe, siła walcowania, smarowanie kotliny walcowniczej.

Streszczenie: W procesie walcowania na gorąco siła konieczna do uzyskania pożądanego stopnia odkształcenia plastycznego materiału w kotlinie walcowniczej jest istotnym parametrem, wpływającym na stopień zużycia walców, prowadzenie pasma w klatkach walcowniczych, kształt i profil walcowanego pasma oraz zużycie energii elektrycznej. Efektywnymi sposobami zmniejszenia siły koniecznej do odwalcowania pasma w grupie klatek wykańczających mogłoby być prowadzenie walcowania w wyższej temperaturze i z mniejszymi prędkościami lub zmniejszenie wejściowej grubości pasma. Z uwagi na wymagane własności mechaniczne blachy po walcowaniu na gorąco, a także ciągłe dążenie do zwiększenia wydajności linii i optymalizacji kosztów, najczęściej nie jest to możliwe. Skutecznym sposobem pozwalającym na zmniejszenie siły walcowania jest zastosowanie smarowania kotliny walcowniczej. Zmniejszenie tarcia pomiędzy powierzchnią walców i walcowanym materiałem pozwala uzyskać spadek siły na poziomie 5–20%. Spadek siły walcowania przekłada się wprost na zmniejszenie zużycia energii elektrycznej, jednak najważniejsze są korzyści związane ze zmniejszonym zużyciem walców roboczych i lepszą kontrolą kształtu pasma. Kwestie te nabierają szczególnego znaczenia podczas produkcji blachy o strukturze dwufazowej, która z uwagi na wymaganą stosunkowo niską temperaturę końca walcowania charakteryzuje się dużym oporem odkształcenia skutkującym występowaniem dużych sił w trakcie walcowania w grupie klatek wykańczających.

INTRODUCTION

The force required for plastic deformation of rolled material in the hot rolling process can reach up to 40000 kN. Some steel grades exhibit high yield stress during hot rolling, despite the elevated temperatures at which this process occurs. Several factors influence roll force, among which the most essential are strip temperature in roll gap, thickness reduction in each pass, strip width, rolling speed

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and coefficient of friction between strip surface and work rolls surface **[L. 1, 2]**. In modern hot strip mills, the force required for plastic deformation is applied to rolled strips by hydraulic cylinders, commonly known as HGC (hydraulic gap cylinder). The main purpose of HGC is to keep the correct gap between work rolls on the whole length of rolled strip. It is achieved by counteracting to work rolls separating force resulting from the plastic deformation process. Noticeable roll force fluctuations are present in the rolling finishing process due to rolled material's inhomogeneous chemical composition, temperature and entry thickness. Under the loads, during rolling, parts of finishing stands undergo elastic deformation, resulting in roll gap geometry change. Work rolls are flattened, and the finishing stand is stretched. In order to keep the constant thickness at the exit side of each stand, HGC continuously makes small adjustments to the gap between the work rolls. Roll force instability causes disturbances in mass flow between stands, leading to serious problems during rolling, including stopping the line **[L. 3, 4]**. Aside from issues with mass flow, high roll force and its fluctuations can lead to deterioration of strip profile and shape **[L. 5]**. As roll force increases, the bending of work rolls becomes more pronounced. Dedicated hydraulic cylinders counter the work roll bending, but the target strip profile cannot be achieved if the roll force is too high. Therefore, a lower roll force is beneficial from a quality point of view. Another issue related to the roll force is the roll wear. Depending on applied temperatures, rolled steel grades and types of work rolls, wear of its surface can vary **[L. 6]**. Due to technological constraints, temperatures in the rolling gap often cannot be maintained sufficiently low. It is related to the necessary reduction of work roll cooling or interstand cooling during the rolling of some special steel grades. The steel grade itself also has an impact on forces during rolling. Scale grows on the surface of each steel grade, but the thickness and physical properties of the scale can differ from one grade to another. Both the thickness and type of scale (proportions between Fe oxides, brittleness, etc.) at the time of strip deformation strongly influence friction conditions in the roll gap **[L. 7, 8]**. It is commonly agreed that the friction coefficient in the roll gap during the hot rolling process falls between 0.2 to 0.45 and is one of the most important factors influencing the roll force **[L. 1]**. Many models are currently developed to predict or calculate the actual friction coefficient in the roll gap. The main goal of these models is to improve roll force predictions and mass flow calculations **[L. 9–11]**. Aside from mentioned matters related to strip quality and work roll wear, friction in the roll gap also tremendously affects energy consumption in hot strip mills. A higher roll force means a higher torque, which results in higher power consumption by finishing stands motors. In the literature, apart from research concerning the use of different lubricants and their influence on friction coefficients, the lubrication of back-up rolls is also considered **[L. 12, 13]**. Lowering the friction coefficient at the contact surface between the back-up and work roll may also decrease power consumption. Potential savings are always sought in every hot rolling mill, and the current energy market situation gives a strong incentive for developing and implementing solutions, which can further limit energy consumption costs. This work aimed to evaluate the effect of roll gap lubrication (RGL) on roll force decrease during hot rolling of DP600 steel grade. According to the authors' best knowledge, no publications describe this effect on the example of dual phase steel.

EQUIPMENT AND MEASUREMENTS

This work investigated the effect of roll gap lubrication (RGL) on the decrease of roll force during hot rolling in finishing stands of DP600 steel grade was investigated. DP600 grade is a particular steel characterised by a dual phase microstructure of martensite islands dispersed in a ferrite matrix. Combining those two phases, which greatly differ in mechanical properties, results in a unique set of properties characterised by high tensile strength and good ductility during cold forming. Process technology of dual phase steel requires low final rolling temperature (FRT), which is well below 850°C. Such a low FRT leads to the high yield stress of rolled material and produces a high roll force. **Fig. 1** shows the thermal cycle in the hot rolling process of DP steel from a discharged slab to a finished coil.

In order to decrease roll force and avoid problems related to high load during rolling, RGL is used to lower the friction coefficient. Investigations were carried out on a hot strip mill equipped with 6 finishing stands, out of which stands F2, F3 and F4 were equipped with RGL installation. Presented data were acquired during the hot rolling of DP600

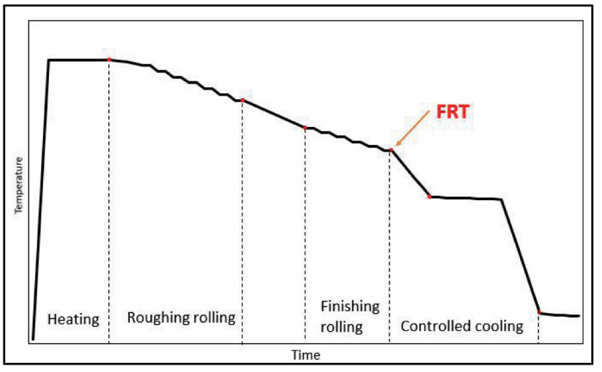

Fig. 1. Thermal cycle in hot rolling of DP600 steel grade
Rys. 1. Cykl termiczny w procesie walcowania na gorąco stali w gatunku DP600

strips with a thickness of 4.2 mm and a width of 1440 mm. RGL installation applies a mixture of oil and water on the surface of the top and bottom work rolls. A schematic view of the RGL installation of the top work roll is shown in **Fig. 2**. RGL nozzles spread the oil on the work roll's surface on the mill's entry side. Oil is applied just above the work roll cooling (WRC) headers. Therefore, the WRC on the entry side has to be switched off during RGL working. If the WRC is not switched off, then water coming from these headers would wash away oil from the surface of the rolls before it could reach the roll gap.

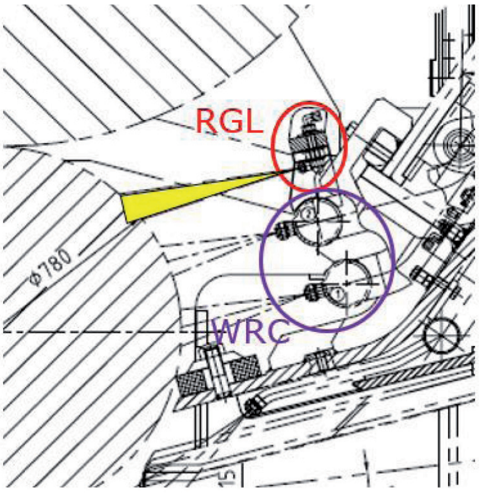

Fig. 2. Roll gap lubrication – top work roll schematic view
Rys. 2. Instalacja smarowania kotliny walcowniczej – schemat dla górnego walca roboczego

A mixture of water and oil, with an oil content of about 1–2%, is applied on the work rolls' surface by nozzles, as shown in **Fig. 3**. Mineral oil is used as a lubricant with a density of 0.92 g/cm3 and kinematic viscosity of 54.5 mm2/s at room temperature. The working pressure for the RGL installation is about 6 atm, and actual oil flows range from 15 ml/min to 35 ml/min depending on the rolled thickness and steel grade.

Fig. 3. Roll gap lubrication installation – oil nozzles
Rys. 3. Instalacja smarowania kotliny walcowniczej – dysze olejowe

The roll force is continuously measured during the rolling of each strip using pressure transducers installed in each HGC. Given that the dimensions of HGC are known, the proportion of pressure measured on the piston and the rod side of the cylinder is then calculated for the correct force. The increases in the roll force, strip entry temperature and rolling speed during the rolling of DP600 steel are shown in **Fig. 4**. During hot rolling, a steady increase in roll force is usually observed. It is caused by the cooling down of the strip at the entry to the first finishing stand. Due to a gradual decrease in the strip's temperature, the force required for its deformation constantly increases. Additionally, FRT has to be stable and within the given tolerances for the whole length of the strip. **Fig. 4.** presents a case where the roll force increases from 26000 kN to 34000 kN, the strip entry temperature decreases from 1040°C to 950°C and the rolling speed increases from 0.9 m/s to 1.15 m/s.

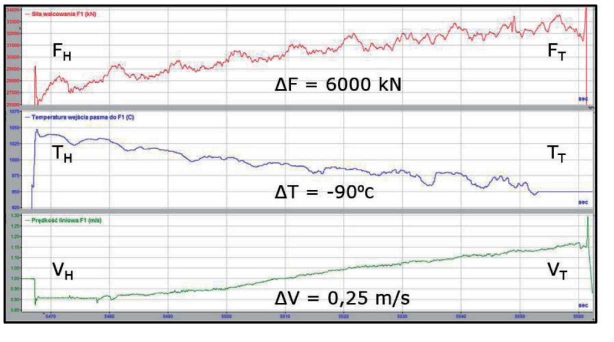

Fig. 4. Roll force, strip entry temperature and rolling speed increase during rolling of DP600 strip
Rys. 4. Zmiana siły walcowania, temperatury wejściowej pasma oraz prędkości walcowania podczas walcowania pasma DP600

In order to achieve a constant temperature at the exit of finishing mills, while strip temperature at the entry decreases with every second, it is necessary to increase the speed of the rolling process. Increasing the speed during rolling increases the strain rate, which results in more heat produced during plastic deformation. The heat produced from the high strain rate compensates for the temperature drop at the entry to the mills. Both the strain rate increase and temperature drop are the reasons for an observed steady increase of roll force at the time of rolling.

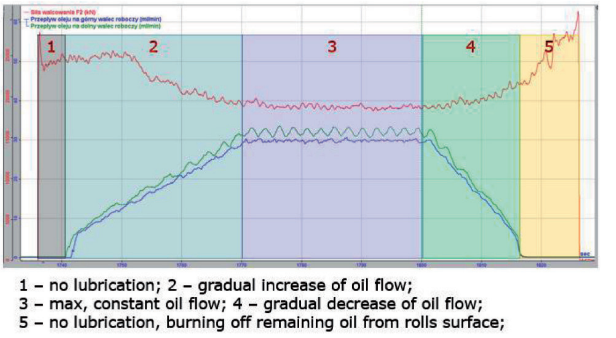

Fig. 6. Change of oil flow during rolling
Rys. 6. Zmiana przepływu oleju w trakcie walcowania

RESULTS AND DISCUSSION

Using oil to lower the friction coefficient gives visible results in decreasing roll force. **Fig. 5** shows the roll force on each finishing stand. The roll force on each next stand is usually lower than on the previous one due to decreasing thickness reduction from stand F1 to F6. The work of RGL can be divided into five stages.

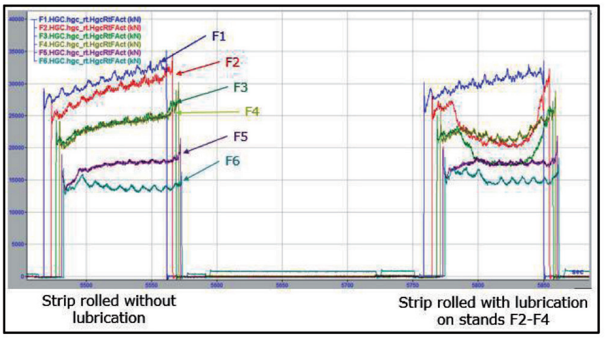

Fig. 5. Roll force on each finishing stand for strips rolled with and without roll gap lubrication
Rys. 5. Siła walcowania na wszystkich klatkach wykańczających dla pasma walcowanego z oraz bez smarowania kotliny walcowniczej

In **Fig. 6**, the red line shows roll force, and lines blue and green show oil flow on the top and bottom work roll, respectively.

The first stage lasts a few seconds; during that time, there is no oil flow through the RGL installation. At that time, the strip head threads through the subsequent finishing stands. This is the only part of the rolling process in which high friction coefficient is advantageous. At this stage of the rolling process, too low friction could lead to thread-in refusal, and as a consequence, the strip could be stuck at the entry to the mill stand, causing line stoppage. Once the head end of the strip passes through all finishing stands, the oil flow slowly starts increasing. Oil flow increase at stage two cannot be too sharp because a rapid change of friction coefficient in the roll gap could destabilise the rolling process. Stage three starts after reaching the target oil flow, and then RGL works with the maximum oil flow set for that strip. The highest roll force decrease due to RGL is observed at this stage. Stage four starts with a gradual decrease in oil flow. The oil flow decrease cannot be too sharp for the same reasons as in stage two. Stage five, like stage one, takes place with no lubrication. The oil flow stops at least a few seconds before the rolling ends, giving time for burning off the remaining oil from the work roll's surface. This is the most efficient way to remove all oil from work rolls so that next strip can pass through the rolls with no oil on its surface, reducing the risk of thread-in refusal. **Fig. 7** shows two similar strips of DP600 steel rolled one after another. The red lines show roll force on stands F2 and F3 for strips rolled without RGL, and the green lines show the roll force on the same stands for a strip rolled with RGL. The

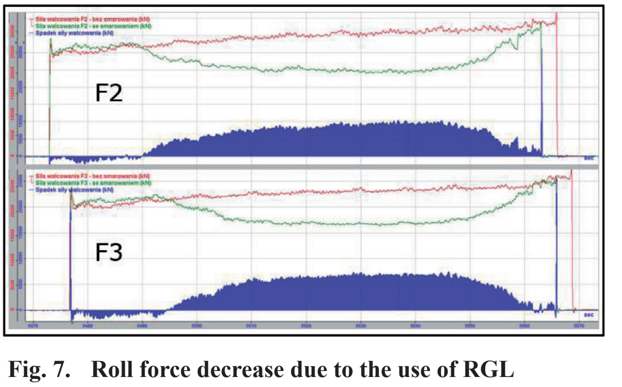

Fig. 7. Roll force decrease due to the use of RGL
Rys. 7. Spadek siły walcowania dzięki zastosowaniu smarowania kotliny walcowniczej

blue fields on the graphs represent the calculated difference between the force required for rolling a strip with and without RGL. It can be seen that after reaching a maximum oil flow, the roll force decrease can be as high as 10000 kN on stand F2 and 7000 kN on stand F3. This is about 30% of the force required for the strip's deformation without lubrication.

The roll force decrease corresponds to a similar power consumption decrease by finishing stands' motors. Based on historical data from the hot strip mill database, power consumption drops on average by 15% when RGL is used. The average roll force decrease on the whole length of the strip (including parts rolled without RGL) differs between stands (**Fig. 8**).

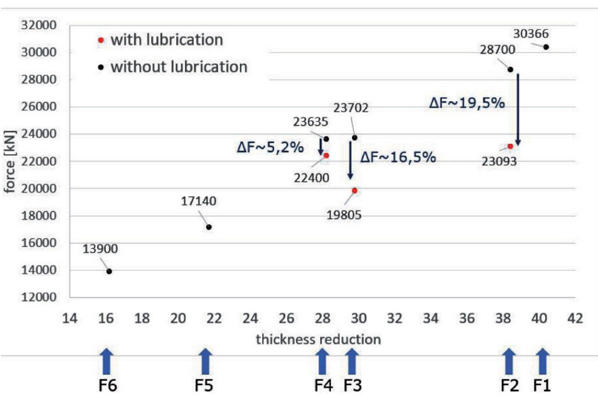

Fig. 8. Average roll force decrease at each stand due to RGL

Rys. 8. Średni spadek siły walcowania dzięki zastosowaniu smarowania kotliny walcowniczej

The biggest roll force decrease is achieved on stand F2, a smaller decrease is seen on stand F3 and on the stand F4 roll, and the decrease is the lowest, about four times smaller than on stand F2. The reason is that the strip's length is different on each rolling stand. Due to elongation in the rolling process, the length of the strip rolled in stand F3 is about 40–50% greater than in F2. Similarly, the length of the strip rolled in stand F4 is about 30–40% greater than in F3. Differences in the rolled length between stands are proportional to a thickness reduction in each stand. Increasing a strip's length requires increasing rolling speed in every next stand. The total oil flow in RGL installations is similar on stands F2, F3 and F4, but the oil flow in reference to a rolled length of the strip is much different for each stand. The amount of oil used for each meter of the strip rolled in F4 is much lower than in stand F2. RGL nozzles are situated in the mill stand in such a way that for the working time of RGL, the worked roll cooling on the entry side of the mill has to be switched off. It is to not wash away the oil from the roll's surface before reaching the roll gap. In practice, it means that the work roll's cooling is reduced by 50% when RGL is used. Therefore, it could be expected that the work roll's temperature at the end of the rolling campaign on stands with RGL will be higher than on stands without RGL. In fact, it is the opposite. By using a portable hand pyrometer, the temperature of the roll's surface has been measured. The work roll's temperature measurements performed on stand F1 (without RGL, **Fig. 9**) and stand F2 (with RGL, **Fig. 10**) show that despite a reduced work roll cooling flow, rolls from stand F2 have a lower temperature than rolls from stand F1. The influence of lowered friction coefficient can explain this effect on the heating of rolls during rolling. In some cases, lowering the friction coefficient seems more effective than cooling work rolls.

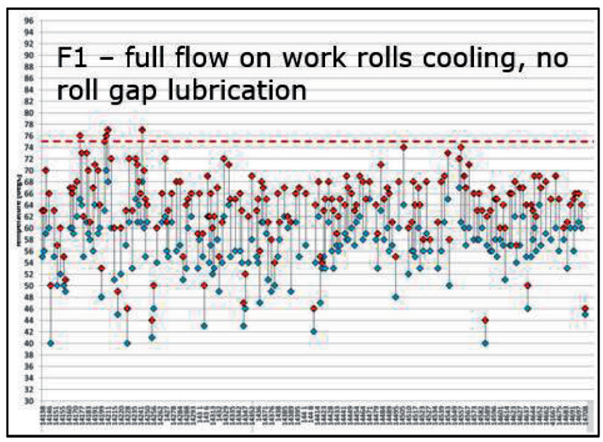

Fig. 9. Stand F1 top and bottom work rolls temperature after rolling campaign (red and blue dots respectively)

Rys. 9. Temperatura górnych oraz dolnych walców roboczych na klatce F1 po kampanii walcowniczej (odpowiednio czerwone i niebieskie punkty)

Using RGL gives many benefits but can also create problems that otherwise would not be present. As mentioned, at the end of rolling, the oil flow is switched off to burn off the remaining oil from the roll's surface. It leads to a sharp increase in roll force at the very end of the rolling process. Once the oil flow drops to zero, the friction coefficient rapidly increases, which causes a sudden rise in the roll force. This effect is shown in **Fig. 11**, where two strips are compared. Strip on the left was rolled without RGL, strip on the right was rolled with RGL.

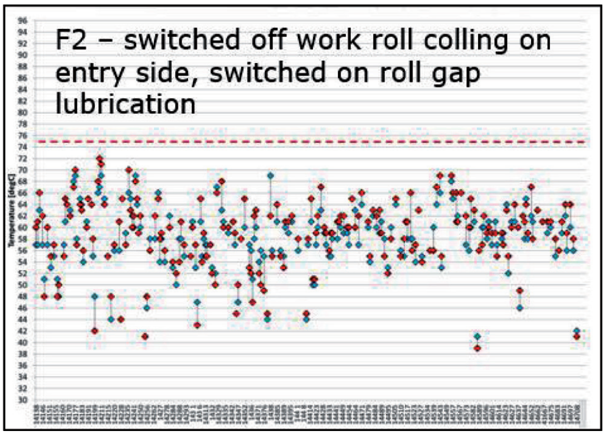

Fig. 10. **Stand F2 top and bottom work rolls temperature after rolling campaign (red and blue dots respectively)**

Rys. 10. Temperatura górnych oraz dolnych walców roboczych na klatce F2 po kampanii walcowniczej (odpowiednio czerwone i niebieskie punkty)

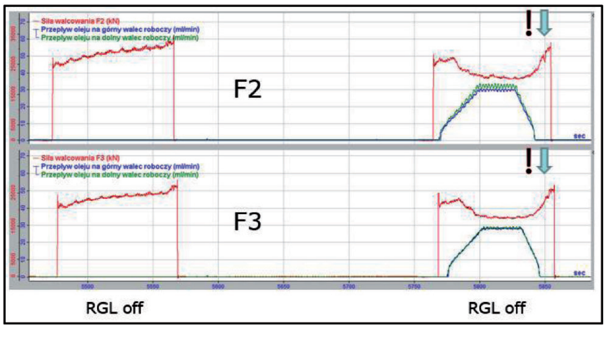

Fig. 11. **Sharp increase of roll force at the end of rolling due to RGL switch off**

Rys. 11. Gwałtowny wzrost siły walcowania na końcu pasma spowodowany wyłączeniem smarowania kotliny walcowniczej

This phenomenon has a negative impact both on the work roll's fatigue resistance and on the rolling process stability. In most adverse cases, such a sharp increase of roll force can cause damage to the strip's tail end and, consequently, stoppage of the line. Therefore, ongoing investigations aim to find a new solution for removing oil from the work roll's surface. One of the possible solutions concerns using detergent, which could be applied on the work roll's surface together with cooling water. In that case, oil could be removed from rolls in time between strips.

CONCLUSIONS

Roll gap lubrication in the hot rolling process results in a visible decrease of the roll force, reaching up to 30% of the force required for the plastic deformation of rolled material. The average decrease of roll force while rolling one whole strip of DP600 steel grade ranges from 5% to 20% and is higher in early finishing stands (F2) than in later stands (F4). The roll force decrease results in about 15% lower power consumption of finishing stands' motors. A lower friction coefficient results in lower work rolls' surface temperature, positively affecting work rolls' wear. Although RGL installations have been used in many mills for decades, there is still room for improvement. The problems related to mass flow disturbances experienced at high oil flows and sharp increase of roll force at the end of rolling remain unsolved. Once a reliable solution for these issues is provided, it may be possible to increase oil flow during rolling, and by doing this, the benefits experienced by using RGL could be increased.

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