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EFFECT OF CASTING PARAMETERS ON MICROSTRUCTURE, RECRYSTALLIZATION BEHAVIOUR AND FINAL MATERIAL PROPERTIES OF TWIN-ROLL CAST 1050 ALLOY

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Abstract

Aluminium alloys produced by twin-roll casting exhibit inherently existing features due to distinctive solidification behaviour encountered during casting. Contrary to fine intermetallic particles observed at the outermost surface, centerline segregations enriched in solute elements reside at the mid-plane of cross-section. These morphological and compositional discrepancies are affected by casting parameters and resultant heat extraction due to separating force exerted by solidifying metal. In that respect, materials produced with different set of casting parameters were exposed to different thermo-mechanical processes to elucidate recrystallization and grain-growth behaviour inherited by initial as-cast microstructure. Microstructures were investigated by employing metallographic techniques throughout downstream processes. Complementary studies were performed by electrical conductivity measurements, tensile tests, micro-hardness tests and corrosion tests. Results show that microstructural properties of as-cast sheet can be tailored with defined combination of casting parameters. This also results in different material properties to evolve as they are exposed further annealing and rolling operations.

Introduction

Twin roll casting (TRC) is a proven technology for economical production of thin aluminium sheet directly from the melt [1, 2]. In TRC, molten metal is fed between water cooled rolls, where it solidifies and then rolled. Processing cost of TRC is significantly lower when compared to conventional direct-chill casting. On the other hand, TRC has some characteristic features. With the high cooling rate achieved through water cooled rolls, TRC materials have rapidly solidified surfaces. Related with that, these materials have smaller grain sizes on their surfaces than that of the center. Heterogeneous distribution of intermetallics, dispersoids and eutectic structures can be encountered through thickness [3-5].

Separating force, which is an important outcome of applied set of casting parameters in TRC, influences the heat extraction from liquid metal and plays an important role in solidification behaviour of the metal by dictating the morphology and distribution of secondary phases in matrix and development of grain structure [1, 3]. These inherited characteristics reveal themselves at all stages during downstream processes by affecting texture development and recrystallization behaviour of the metal.

Experimental Studies

Alloy 1050 samples processed and investigated in the scope of this study, were produced via a Fata Hunter speed-caster. Chemical composition is given in Table I.

The speed of the rolls were decreased gradually during casting along with the roll gap to prevent an increase in thickness of as-cast samples, which resulted in a considerable increase in separating force exerted on the rolls. As-cast samples were collected at each different casting speeds such as 1.9, 1.5 and 1.1 m/min. Table II shows the change in separating force due to varying casting speeds. As-cast samples produced with mentioned casting speeds were processed in laboratory by utilizing a laboratory-scale rolling mill and annealing furnaces. Different downstream processes were conducted to obtain a final thickness of 1.2mm as shown in Table III. Homogenization or intermediate annealing was applied at 3mm except process no 4 which was conducted with only back-annealing.

Table I. Chemical composition

Element, wt. %							
Si	**Fe**	**Cu**	**Mn**	**Mg**	**Zn**	**Ti**	**Al**
0.10	0.273	0.001	0.005	0.002	0.013	0.011	99.56

Table II. Sample codes and related casting parameters

Sample Code	Casting Speed (m/min)	Separating Force (tons)	Headbox (°C)	Setback (mm)	Thickness (mm)
A	1.9	1300	718	69	4.91
B	1.5	1790	715	69	4.99
C	1.1	2140	715	69	5.05

Table III. Downstream processes applied

Process Code	Homogenization @3mm	Intermediate Annealing @3mm	Back-Annealing @1.2mm
1	520°C-5h	-	410°C-3h
2	520°C-10h	-	410°C-3h
3	-	410°C-3h	410°C-3h
4	-	-	410°C-3h

Microstructures of as-cast materials and the samples at each stages of applied thermo-mechanical processes were investigated by an optical microscope. Mounted samples homogenized or annealed at 3mm thickness were exposed to salt-spray test in order to investigate the behaviour of centerline segregations (CLS) via SEM. Complementary studies were carried out by tensile tests at final thickness, micro-hardness measurements at as-cast thickness and measurements of electrical conductivity at each stage during downstream processes.

Results and Discussion

Figure 1 shows the secondary phases and CLS at mid-plane of each as-cast sample produced by different casting speeds. With decreasing casting speed, CLS formation is gradually diminished and almost disappears at sample C, which is the metal providing the highest separating force. This shows that increased heat extraction from liquid metal helps in trapping the solute elements

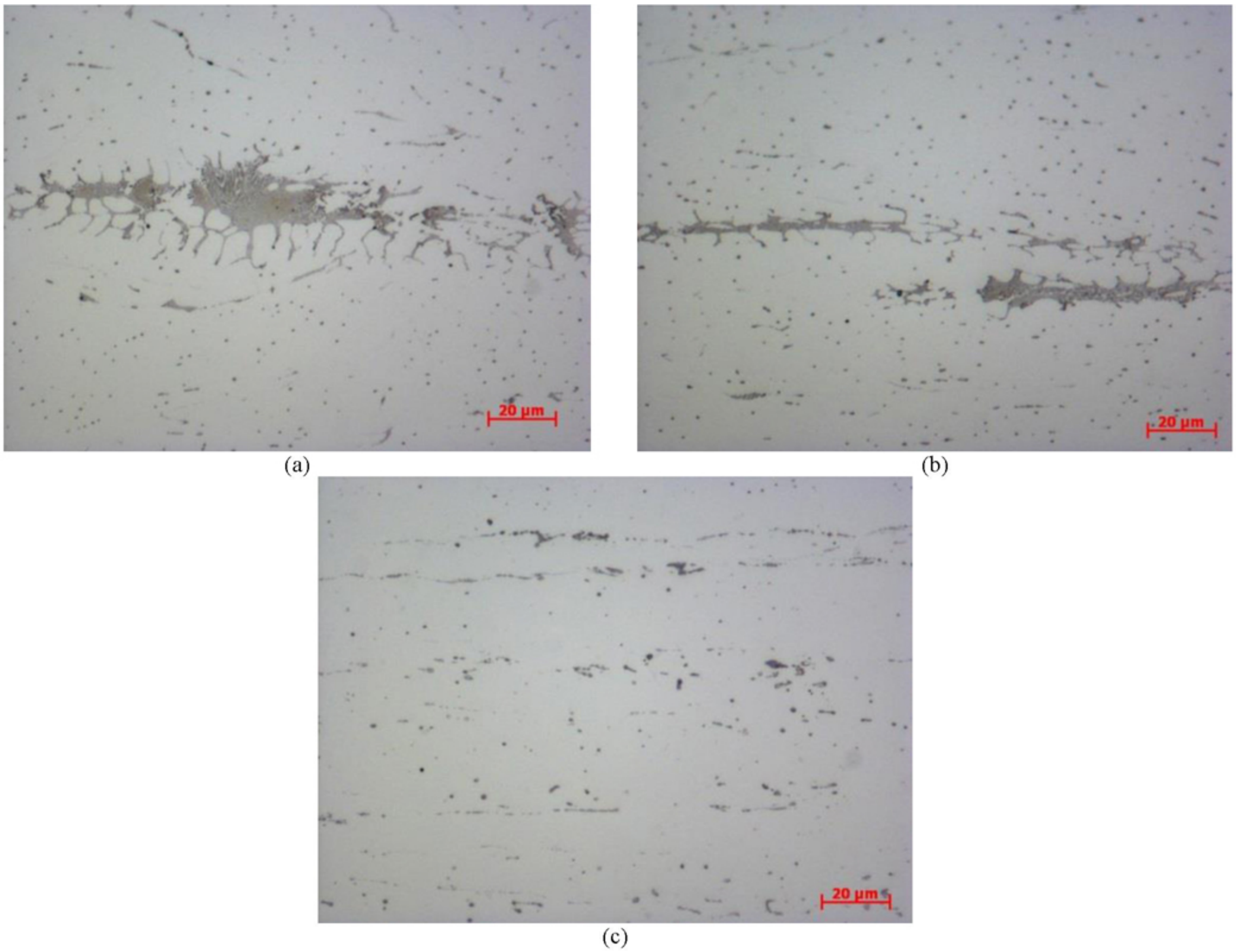


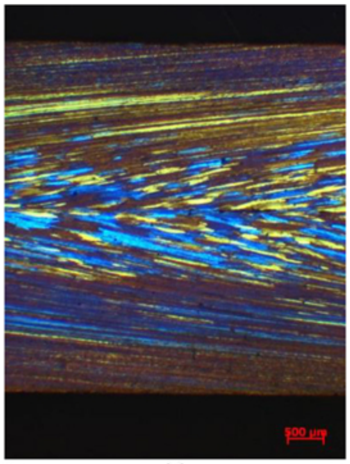
Figure 1. Centerline segregations observed in a) Sample A b) Sample B c) Sample C.

in matrix by obstructing diffusion and prevents them to be swept in front of the solidification fronts to the mid-plane of the cross-section where liquid metal solidifies last due to the gradient of solidification rate through entire thickness. Coarse eutectic colonies can be observed in the centerline of the sample A, whereas they are less in size and magnitude in sample B. In sample C, there are only fine stripes of intermetallic particles aligned parallel to the casting direction and no formation of CLS. Another interesting finding in sample C is the depleted zones by the intermetallic particles in matrix as can be seen in Figure 1-c.

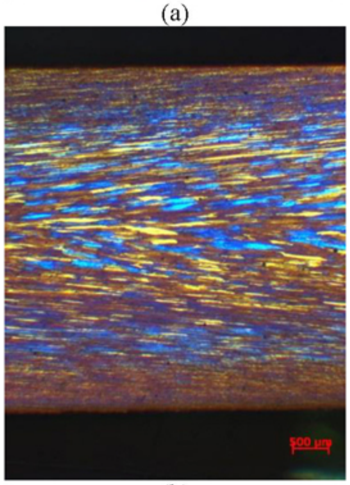
These features can be attributed to the increased solidification rate which is promoted by increased heat extraction by the caster rolls since solidifying metal spends more time in the roll gap as the casting speed decreases. Grain structures of as-cast samples are given in Figure 2. As expected in TRC materials, grain sizes increase gradually from surface to mid-plane. Outermost layers accommodate finer grains with respect to the mid-plane due to the gradient in solidification rate. Another observation is the increasing thickness of the super-saturated zones at the outermost skin of solidified metal with increasing separating force. Thus, super-saturated zones grow deeper and a higher proportion of the cross-section is occupied by fine grains. However, a steep transition in grain size is observed in sample C instead of a gradual change and interestingly there are enormous grains residing at the mid-plane.

Assumed mechanism which can lead to mentioned coarse grains in sample C is; Due to fast cooling related with high separating forces, the outermost skins solidify and grow so fast that these skins might behave as a barrier layer preventing or limiting the contact and heat transfer between liquid metal and caster rolls and inhibit further cooling which result in center zones solidifying more slowly. Thus, grains residing at mid-plane get coarse.

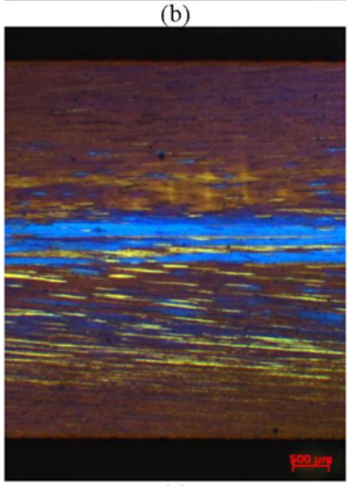
Figure 3 shows Vickers micro-hardness measurements performed on as-cast samples through entire thickness. As separating force increases at the expense of casting speed, hardness values rise at all points including surface, quarter and mid-plane of the samples. Most dramatic change is encountered at the points close to the surface which is in good agreement with microstructures given in Figure 2. This can be correlated with finer grains observed in super-saturated zones due to increased heat extraction and cooling rate. Hardness gradient between surface and mid-plane extends with increasing separating force. Hardness of sample A is almost stable between 38-40 HV throughout entire thickness whereas point measurements of sample C fluctuate in a broader range.



(a)



(b)



(c)

Figure 2. Grain structures of a) Sample A b) Sample B c) Sample C.

Figure 4 shows the measurements of electrical conductivities performed at different stages of mentioned downstream processes. As-cast sample A shows highest electrical conductivity when compared with sample B and sample C. Electrical conductivity decreases slightly but gradually as separating force increases and this can be correlated with higher heat extraction and cooling rate which leads to a more super-saturated matrix. Higher electrical conductivity encountered in low separating force as-cast samples can be attributed to the lower cooling rate and thus, higher precipitation. Electrical conductivities decrease as the samples are rolled down to 3mm at which samples are heat treated. This is due to work-hardening and new introduced dislocations. As seen in Figure 4, samples annealed at 410^{o}C exhibit higher conductivity with respect to the homogenized samples at 520^{o}C. This reveals that as the temperature is raised over 410^{o}C, precipitates are in tendency of dissolution within the matrix which impairs conductivity. Duration of soaking also results in similar effect at constant homogenization temperature. As it is prolonged over 5h, the conductivities decrease.

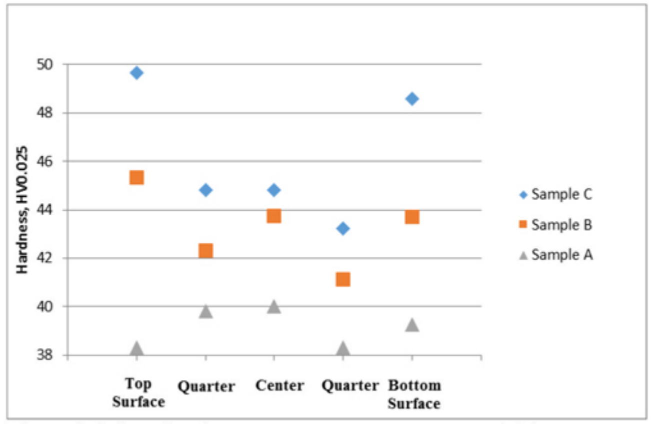


Figure 3. Micro-hardness measurements at as-cast thickness.

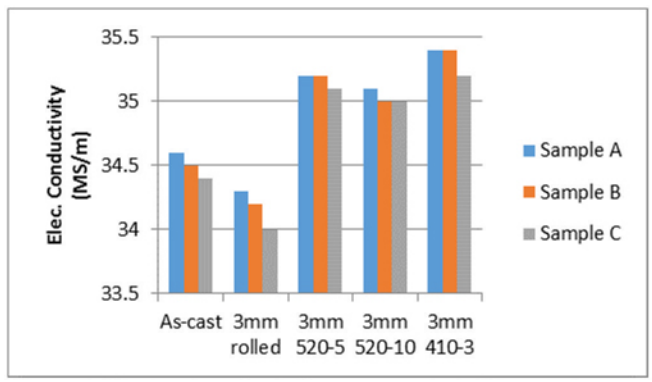
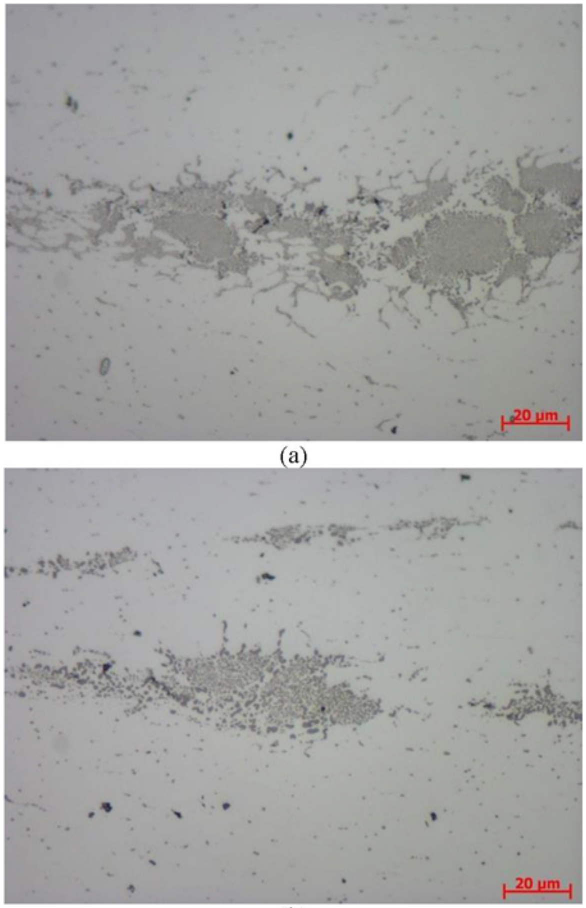


Figure 4. Electrical conductivities measured at different stages of downstream processes.

Figure 5 shows the effect of heat treatments applied at 3mm thickness on the distribution and morphology of the secondary phases. Regardless of the soaking time, homogenization treatment applied at 520^{o}C decomposes the coarse eutectic colonies constituting the CLS into relatively coarse intermetallic particles in sample A and sample B.

EDS analysis (Table IV) performed at 3mm reveals that applied annealing temperature does not only change the morphology and distribution of CLS but also alters the chemical composition of these secondary particles. Homogenization treatment at 520^{o}C results in enrichment of Fe and Si contents of secondary particles while decomposing coarse eutectic colonies.

Recrystallization and grain growth behaviours of the samples having different casting speeds are in line with their as-cast grain structures as shown in Figure 6. Grain sizes after heat treatments at 3mm are quite coarse at the mid-plane in sample C which is inherited by its as-cast grain size and distribution. Therefore, it exhibits a heterogeneous grain size distribution regardless of the annealing temperature and time applied. Another observation is the relatively coarser grains observed at homogenized sample C with respect to that of annealed at 410°C. Sample A presents a relatively homogenous grain size distribution which is again inherited by its as-cast grain structure.



(a)

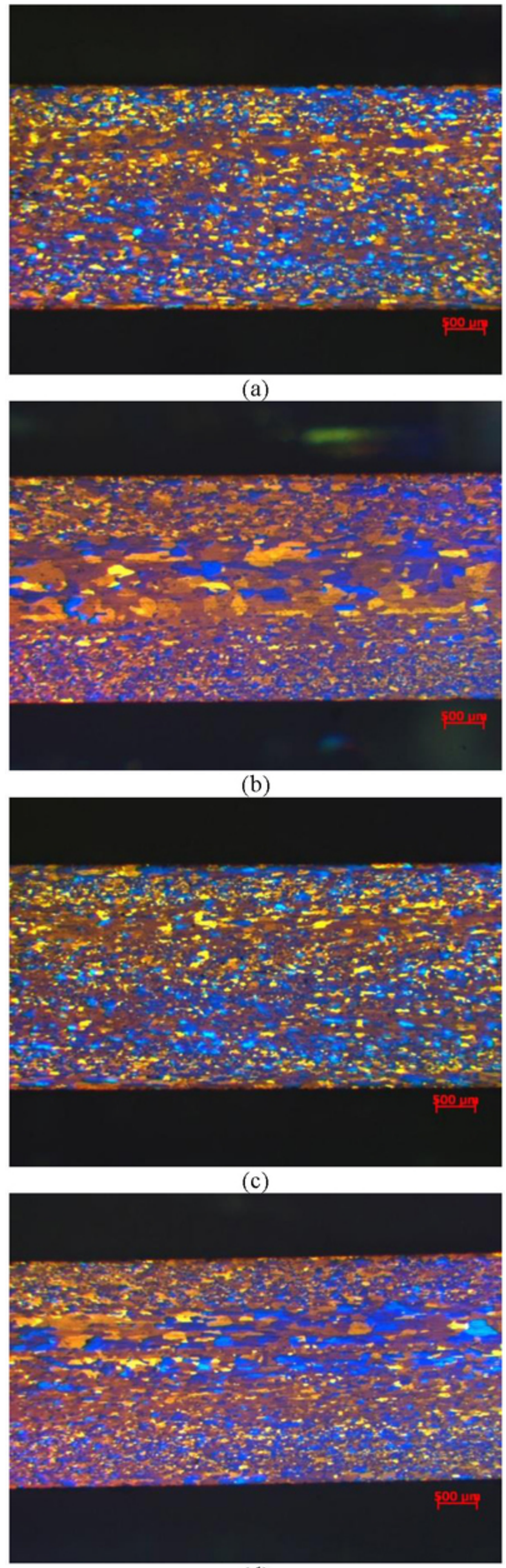
(b)

Figure 5. CLS of sample A at 3mm after a)410 °C-3h b) 520 °C-5h

Table IV. EDS analysis at 3mm after applied heat treatments

Process Code	Homogenization @3mm	Fe content (%)	Si content (%)
1	520°C-5h	10-15	1.5-2.0
3	410°C-3h	6-10	0.5-1.2

Centerline segregations observed in TRC materials are known to be preferential sites for the onset of corrosion (6), however type of corrosion failure depends on the electronegativity of intermetallic particles. Potential difference between intermetallic particles and surrounding matrix is the driving force for corrosion. SEM images given in Figure 7 show cross-sections of sample A after 24h salt-spray test. Intermediate annealing applied at 410°C has a negative effect on corrosion behaviour and material loss is observed between coarse eutectic structures and the matrix whereas samples homogenized at 520°C are intact.



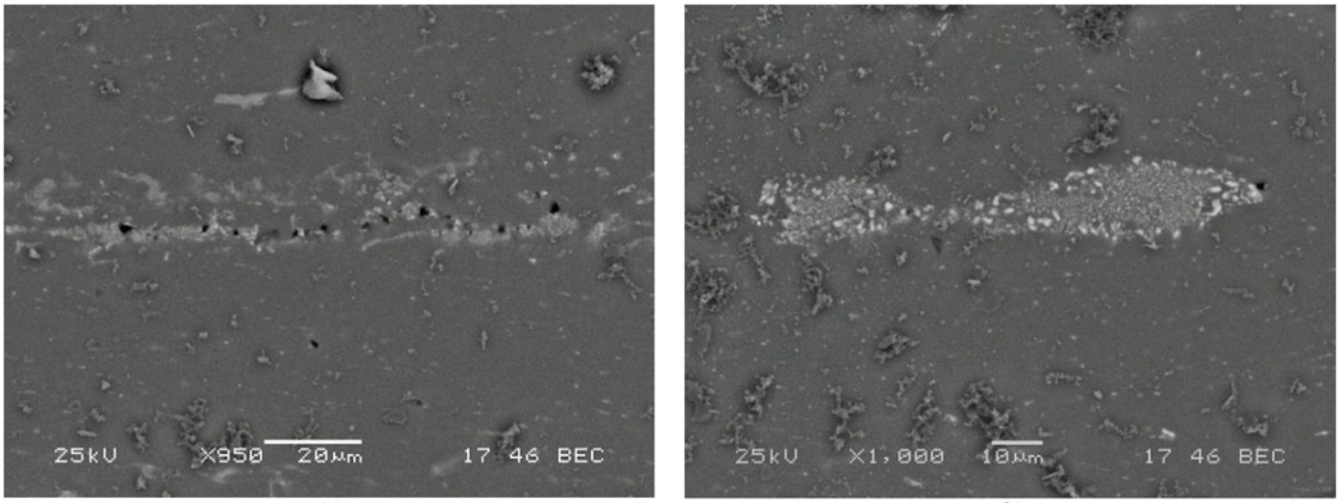
(a)

(b)

(c)

(d)

Figure 6. Grain structures at 3mm after applied heat treatments a)Sample A/520°C-5h b)Sample C/520°C-5h c)Sample A 410°C-3h d)Sample C/410 °C-3h



(a) (b)

Figure 7. CLS of sample A at 3mm after 24h of salt-spray test a)410 ^{o}C-3h b)520^{o}C-5h

Similar effect had been experienced in a study involving brazing alloys used in heat exchanger systems (6). However, salt-spray test has to be prolonged to elucidate the exact corrosion behaviour of CLS encountered in 1050 alloy. Depending on the behaviour of CLS and intermetallic particles, failure may proceed either with loss of material at the interface between CLS and surrounding matrix or decomposition of CLS itself.

Tensile tests performed at 90^{o} with respect to rolling direction at 1.2 mm are listed in Figure 8. It is clearly seen that homogenization treatment applied at 520^{o}C decreases yield and tensile strengths and increases elongation which will serve to improve the formability of the materials. Highest tensile strengths were obtained in samples processed with only back-annealing operation. Decreasing casting speed was found to have a slightly negative effect on elongation values due to heterogeneous grain structure evolved after downstream processes which is inherited by as-cast microstructure.

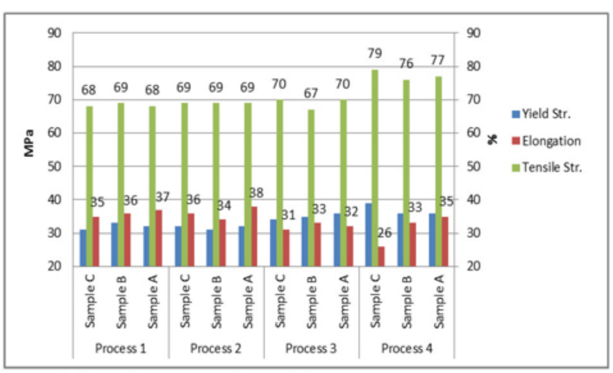


Figure 8. Tensile test results at 1.2mm

Conclusion

Centerline segregation (CLS), which is an inherent characteristic of twin-roll casting, can be controlled by manipulating casting parameters such as casting gauge, casting speed etc. In this study, separating force was found to be a very critical parameter dictating the solidification behavior of the metal. Morphology and distribution of secondary phases including CLS and grain structures strongly depend on separating force exerted on the caster rolls. These micro-features are inherited to down-gauges in different ways depending on the thermo-mechanical processes applied. Results show that separating force and its contributers can be designed in such a way that aluminium produced by TRC can provide tailor-made solutions for different application areas depending on their specific expectations.

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