



Enhance Wear Resistance of Low Alloy Steel Surface in Wood Chipping Mill: Study Hard-facing by SMAW AWS e Fe Cr – a1

Budi Ari Sasmito Simatupang^{1,*} and Priyo Tri Iswanto¹

¹ Department of Mechanical Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia

Corresponding author's email:
budiarisasmitosimatupang@mail.uqm.ac.id

Abstract. Application of low alloy steel in the wood processing in pulp and paper mills is widely used due to its strength and ease of forming. However, Low wear resistance due to friction makes the service life short and thus uneconomical. Increasing the wear resistance of the surface by hard-facing is an attractive solution and easy to implement. This study aims to evaluate the effectiveness of hard-facing welding in improving wear resistance, hardness, and observe the microstructure. Hard-facing process is carried out by SMAW (Shielded metal arc welding), AWS (American Welding Society) e Fe Cr-a1 electrode 4 mm diameter, current (170, 175, 180, 185, 190 A) polarity DC+ welding position 1G and consists of 1 layer. The increase in specific wear resistance from the OAT-U Universal Wear Tester test results and the increase in surface hardness are proportional after hard-facing. In this study, Specific wear and surface hardness of the specimens were found to be better with SMAW welding at 185 A. The specific wear (Ws) of the specimen after Hard-facing SMAW 185A is 0.000382 mm²/kg, surface hardness 476 Hv. Before hard-facing, the specific wear value was 0.002146 mm²/kg and the surface hardness was 96 Hv. The specific wear resistance increased by 5.6 times and the surface hardness by 4.95 times.

Keywords: Hardfacing, Wear, Hardness, Low Alloy Steel, SMAW.

1 INTRODUCTION

Low alloy steel materials are widely used in the wood processing mills in the pulp and paper industry due to their advantages in terms of strength and ease of forming, but have the disadvantage of not having good wear resistance capabilities [1]. The constant friction of wood and impurities on the surface of equipment causes wear and tear resulting in short equipment life, increasing production costs. A surface that is wear resistant, hard and able to be worked with in a short period of time is required. Surface overlays with a deposit of hard material to improve wear resistance capability by welding SMAW is one of the effective and rapid methods in direct application in the industry already in operation [2]. It will increase the service life of the work equipment and will certainly also be more cost-effective, where the work equipment which is a low alloy steel material with lower wear resistance, surface hardness, but after the hard facing process, the wear resistance of the surface hardness increases several times so that the service life of the work equipment also increases several times. Hard-facing of

mild steel A36 by SMAW welding using zed alloy 550 and Nikko steel Hv-600 electrodes with 1 layer and 2 layers applications resulted in wear resistance up to 5.5 higher than the base material [3]. Hard-facing on the surface of Fe-based materials by FCAW welding method with the use of 1 layer & 2 layers with Ar-20%CO₂ shielding gas and without shielding gas resulted into hardness of 780 - 1020 Hv [4]. Hard-facing of EN-8, EN-9 and EN-24 mild steel by TIG (Tungsten Inert Gas) welding electrode ER70S-2 improves the wear & corrosion resistance ability of the material before hard-facing [5]. Wear resistance is closely related to the hardness and also to the uniformity of the microstructure [6]. The objective of this paper is to investigate the optimum parameters in welding hard-facing (current) to enhance surface hardness, wear resistance caused friction on the surface of low alloy steel equipment at wood chipping mill by SMAW welding process 1 layer, 1G position, electrode AWS e Fe Cr-a1 electrode chemical composition C, Cr, Si, Mn, Mo, Ni, rod diameter of 4 mm, polarity DC +, so that it becomes a recommendation in conducting equipment maintenance to increase service life, as to observe the effect of welding parameters on the content of electrode composition and examine the microstructure on the surface of low alloy steel before and after hard-facing.

2 EXPERIMENTAL DETAILS

2.1 Selection of Base Material

Low alloy steel material which is found in wood processing equipment in the pulp and paper industry is the base material in the research conducted. The chute section at the chipping point is the source of sampling because it is the dominant part of abrasion and surface contact with wood and its impurities. Abrasion of equipment surfaces where there is three-body abrasion friction between the hard surface of the equipment and the soft surface of the wood and where hard abrasives of silica, soil or stone enter the processing line [7]. Samples were taken using the same material as the part chute in **Fig. 1** and then formed into the specimens in **Fig. 2** for use in this experiment. Chemical composition of low alloy steel and electrode is shown in **Table 1**.

Table 1. Chemical composition of Low alloy steel take sample from equipment and electrode AWS e Fe Cr-a1 (%)

Material	C	Si	Mn	P	S	Cr	Mo	Ni	W
Low Alloy Steel	0.396	0.209	0.781	0.0465	0.0242	0.113	0.0082	0.0429	-
Electrode Deposit	5.22	2.15	1.31	-	-	32.5	0.02	0.11	0.01



Fig. 1. Chute for sampling.



Fig. 2. Specimen formed.

2.2 Electrode Selection

NX100-4mm AWS e Fe Cr-a1 **Fig. 3** is a SMAW welding wire containing C, Cr, Si, Mn, Mo, Ni. Cr content is one of the most favourable combinations for hardness, wear resistance due to the effect of carbides formed and the effect of Mo content to improve corrosion resistance [8], [9], [10], [11], [12]. Electrode code AWS e Fe Cr-a1 indicates the content of the hard-facing electrode, electrode with Fe Cr content and a1 refers to the presence of Mo content in the electrode [16].



Fig. 3. NX100-4mm AWS e Fe Cr-a.

2.3 Welding Process and Procedures

The Hard-facing welding process in this experiment is using SMAW polarity DC+ and with a 4 mm diameter electrode and position 1G. 1G welding position in a direction perpendicular to the ground or surface to be hardfaced [13]. This is carried out to adapt to the conditions when maintenance activities are carried out on the equipment. The

welding process was carried out on the surface of the base metal with dimensions 70 x 200 mm and 12 mm thick with a single layer and welding current parameters (170, 175, 180, 185, 190 A). The current rate during the welding session is highly important in melting the electrode as well as the depth and penetration on the specimen surface [14]. Each variation of current will have one sample each and the total number of samples will be 5 at the end of the hard-facing welding process.

3 SAMPLE PREPARATION AND TESTING

15 samples were prepared depending on the type of test to be performed. Microstructure observation samples were cut with EDM, and for hardness and wear test samples, the surface was first flattened on a magnetic grinding table **Fig. 4** and then cut using a saw with coolant to comply with the dimensions of the test. In this experiment, there are 3 types of tests that will be carried out to evaluate the results before and after hard-facing welding.

1. Wear testing with High-speed universal wear testing machine Type OAT-U
2. Hardness testing Hv scale
3. Microstructure examination

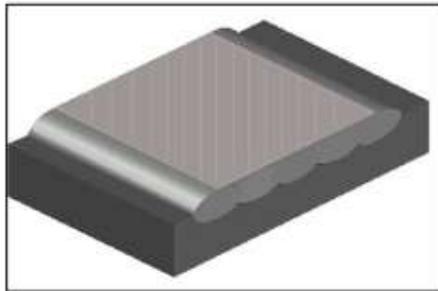


Fig. 4. NX100-4mm AWS e Fe Cr-a.

3.1 Wear Testing with High-Speed Universal Wear Testing Machine Type OAT-U

In the High-speed universal wear testing machine Type OAT-U **Fig. 5** works by means of a rotating disc on the test machine rubbing the surface of the object to be tested for its specific wear value, pressure or load is applied to the surface contact of the specimen against the rotating disc during the rubbing process, the length of the track during friction is determined based on the type of material to test for specific wear. The same thing happens with the wear that occurs on wood processing equipment in mills where the continuous friction occurs between wood and the surface of work equipment so that the surface is subjected to wear damage. The pressure during friction depends on the weight of the wood rubbing and the length of the track according to the wood that moves and passes from above the surface of the equipment while the machine is operating. Specimens that have been customized with dimensions 60 mm

long and 25 mm wide and 10 mm thick are clamped to the grip of the testing machine. The test parameters are configured and the specimen's surface contact with the testing disc is maintained. The trace of friction left on the surface of the specimen in accordance with the load and length of the test track is then analyzed using a microscope to assess the width and length of the trace left on the surface.

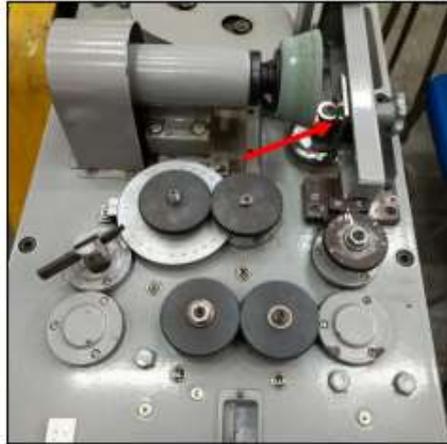


Fig. 5. High-speed universal wear testing machine Type OAT-U.

3.2 Hardness Testing (Hv)

Hardness testing (Hv) Hardness testing was conducted using a Mitutoyo HH-411 Rebound type portable Hardness Tester Fig. 6. The Mitutoyo HH-411 Rebound type portable surface hardness tester is in accordance with ASTM standards A956 [17]. Previously, the surface of the specimen was levelled and smoothed. During the test, the detector is positioned straight on the surface to be tested, and once the button is pressed, the impact hammer and tungsten carbide ball will impact the surface of the specimen. The hardness value displayed on the screen represents the hardness of the surface in Hv scale and the test results of each sample after hard-facing welding on the surface will be evaluated later.



Fig. 6. Mitutoyo HH-411 Rebound Hardness Tester.

3.3 Microstructure Observation

Microstructure examination of the specimens using an Olympus BX53M microscope **Fig. 7**. Microstructural examination was carried out on the hard-facing area, the base metal, and transition area between the base metal and the hard-facing area with $50\mu\text{m}$ visualization. Prior to microstructural examination, the specimens were treated with etching to corrode the surface of the base metal as well as the welding hard-facing parts so that it could be viewed under a microscope. $\text{HNO}_3 + \text{Alcohol}$ solution with an etching time 10-13 sec was treated on the base metal. $\text{AQUADES} + \text{HNO}_3 + \text{HCl}$ solution with an etching time of 10-12 sec was treated on the hard-facing part. When etching time on base metal specimens and hard-facing parts is too long, observations under a microscope will look dark and unable to observe grain boundaries or the shape of the microstructure on the specimen, and if the etching time is too short the surface has not been corroded so there will be no microstructure visible on the surface. The results of the microstructure examination are presented in **Fig. 10**. And we can see the reason of surface hardening in the hard-facing section and compare it with the one before hard-facing.



Fig. 7. Olympus BX53M microscope.

4 RESULT AND DISCUSSION

4.1 Specific Wear Testing with High-Speed Universal Wear Testing Machine OAT-U

Table 2 presents the specific wear results from the OAT-U High-speed universal wear testing machine. It is seen that the highest wear value is found in the base metal without hard-facing on the surface with a specific wear rate of 0.002145896 mm²/kg, and the minimum specific wear value in the sample after hard-facing the surface with a current 185A is 0.000381774 mm²/kg, resistance to wear due to friction increased by 5.621 times and then followed by hard-facing with welding current 180A, 190A, 175A, 170A with wear resistance increased by 5.496 times, 5.301 times, 3.491 times and 3.315 times and shown in **Fig. 8**, graph between welding current strength parameter vs specific wear value after hard-facing the surface. Specific wear obtained from the test results on the High-speed universal wear testing machine OAT-U is the result of measuring the friction traces left on the surface specimen (*B*) by the test disc (*bo*) divided by the applied test load (*Po*) to the test track length (*lo*) so that the specific wear value is obtained by Eq. (1), where *Ws* represent specific wear in mm²/kg.

$$Ws = B \times bo^3 / 8r \times Po \times lo \quad (1)$$

The increased resistance to abrasion is also followed by an increase in surface hardness values after hard-facing welding as shown in **Fig. 9**. The increase in surface resistance to wear due to abrasion after SMAW hard-facing welding is by the content of the chemical composition of the hard-facing electrode used NX100- 4mm AWS e Fe Cr-a1 **Fig. 3** which is Cr, Si, Mn, Mo, Ni. With this composition, hard carbides are formed on hard-facing surfaces resulting in the formation of surface hardness which is directly proportional to the resistance to wear caused by rubbing.

Selection of welding parameters, current strength, is also important to obtain optimal hard-facing results. This is because if the current set to large and causes excessive heat, will cause the alloying elements burn instead of transforming into carbide hard material, and if the current strength used is too low and will not mix the alloying elements with the base metal material so that a hard layer is not formed and tends to be debris when welding occurs, So that the correct current strength in SMAW hard-facing welding with NX100-4mm AWS e Fe Cr-a1 with Cr, Si, Mn, Mo, Ni content is 185A and this can be applied to the surface of the equipment that has been operating during the maintenance period. In this study, after hard-facing with 185A current was better than other parameters, this is possible because at 185A current the heat that occurs during the melting process of the electrode with the parent metal of the electrode element Cr, Si, Mn, Mo, Ni forms hard kabida formations such as chromium carbide (Cr₇C₃) and is formed when the welding temperature is 185A. However, this needs to be further o served in future research with EDS and SEM observation.

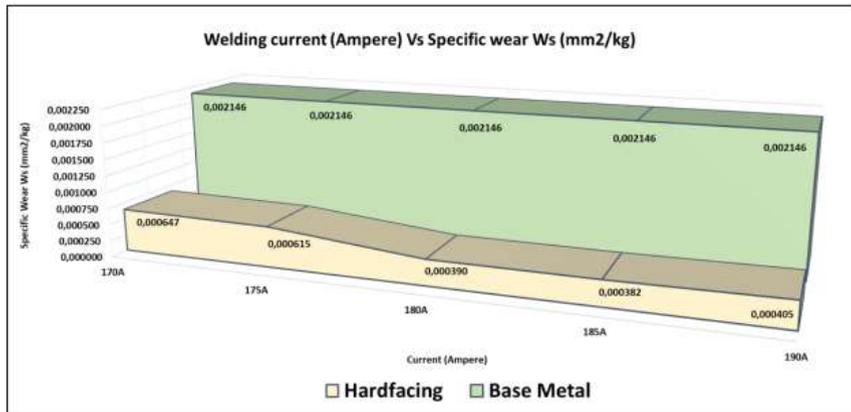


Fig. 8. Current (Ampere) Vs specific wear (mm² /kg).

Table. 2. Specific wear (mm² /kg)

Sample	SMAW welding current (A)	Specific Wear (Ws) (mm ² /kg)
1	Base metal	0,002145896
2	Current 170A 1 layer	0,000647398
3	Current 175A 1 layer	0,000614652
4	Current 180A 1 layer	0,000390432
5	Current 185A 1 layer	0,000381774
6	Current 190A 1 layer	0,000404746

Table. 3. Hardness (Hv)

Sample	SMAW welding current (A)	Hardness (Hv)
1	Base metal	96
2	Current 170A 1 layer	377
3	Current 175A 1 layer	453
4	Current 180A 1 layer	459
5	Current 185A 1 layer	476
6	Current 190A 1 layer	467

4.2 Surface Hardness Test (Hv)

Table 3 shows the results of surface hardness testing on 5 samples and also the results of the test of the base metal surface without welding hard-facing. The surface hardness value of the base metal without hard-facing 96 Hv, and the highest surface hardness value after hard facing 476 Hv increased 4.96 times with a welding current of 185A, with welding currents 190, 180, 175, 170 surface hardness increased 4.87 times, 4.78 times, 4.72 times and 3.93 times. From the results of surface hardness seen in **Fig. 9** is the effect of the electrode content used, such as C, Cr, Si, Mn, Mo, Ni, however, the selection of appropriate welding parameters, SMAW welding current, is a factor to obtain the optimum surface hardness.

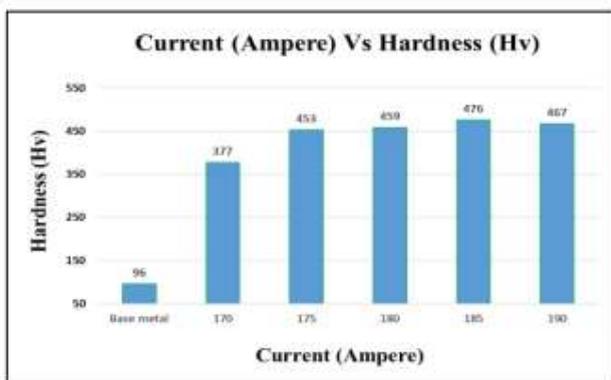


Fig. 9. Hardness result (Hv).

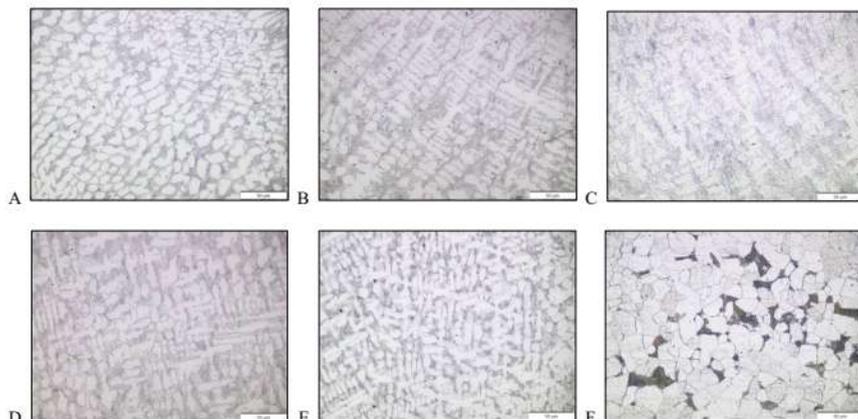


Fig. 10. (A) Microstructure of 170A, (B) Microstructure of 175A, (C) Microstructure of 180A, (D) Microstructure of 185A, (E) Microstructure of 190A, (F) Base Metal.

4.3 Microstructure Examination

Microstructure examination using Olympus BX53M optical microscope **Fig. 7.** on the base metal, the transition region of the weld with the base metal and also on the hard-facing region of the weld deposit with a 50 μ m observation. The etching process is applied first with the purpose of corroding the surface of the material so that it can be viewed under a microscope. HNO₃ + Alcohol solution with an etching time of 10-13 seconds is applied to the base metal. AQUADES + HNO₃ + HCl solution with an etching time of 10-12 seconds was applied to the hard-facing area. **Fig. 10.** shows the microstructure observations on the hard-facing weld deposit where the specific wear and surface hardness test results indicate that samples with 185A current surface hard-facing welding have a minimum specific wear value and a higher surface hardness compared to welding with current of 170A, 175A, 180A, 190A. It appears that on the hard-facing surface with a current of 180A and 185A the distribution of material deposits and grain boundaries is evenly dispersed and uniform. The hard material deposit spreads and becomes more dominant comparing to the hard-facing with the current strength of 170A, 175A, 190A. The difference in the microstructure formation results from variations in welding current is possible due to the welding temperature that occurs during hard-facing with variations in current strength of 170A, 175A, 180A, 185A, 190A is different and the cooling time is also different so that the grain size and grain boundaries are affected.

5 CONCLUSION

The research results can be summarized as the following.

1. Hard-facing of low alloy steel surfaces on wood processing equipment in pulp and paper mills by SMAW welding in 1G welding position with electrode AWS e Fe Cr-a1 rod diameter of 4 mm with current (170,175,180,185,190 A) of DC+ polarity is significantly improved surface wear resistance when compared to the base metal without hard-facing. Wear Resistance improved 5.621 times with current 185A, 5.496 times, 5.301 times, 3.491 times and 3.315 times with welding current 180A, 190A, 175A, 170A.
2. The surface hardness after hard-facing improved 4.96 times with 185A current with 190,180,175,170 welding current the surface hardness improved 4.87 times, 4.78 times, 4.72 times and 3.93 times.
3. Recommendations for the application of 185A current when SMAW hard-facing welding in 1G welding position with electrode AWS e Fe Cr-a1 rod diameter 4 mm DC+ polarity on the surface of wood processing work equipment at pulp and paper mills because it shows maximum results on wear resistance and also hardness values on the surface.
4. The microstructure observation shows that the samples in the SMAW welding hard-facing process with a welding current 185A and 180A show the distribution of material deposits and grain boundaries more evenly and uniformly compared to samples 170A, 175A, 190A.
5. In addition to the chemical composition contained in the electrode (C, Cr, Si, Mn) which affects the formation of a hard surface and wear resistance due to friction, proper welding parameters such as current strength in welding are important because it is proven that different parameters produce different surface hardness and wear resistance [15].

In this research, the problem limitation is only to see the specific wear value and the optimum surface hardness obtained from the SMAW hard-facing welding parameters for low alloy steel material and the number of hard-facing layers is carried out following the actual conditions in the wood processing plant pulp and paper industry, so that it becomes input and reference later in carrying out the maintenance process of work equipment in the wood processing industry in order to increase the service life of the equipment so that it is much more economical. For further research, it is interesting to observe the effect of the number of hard-facing layers (1,2 layers) on wear resistance, surface hardness and corrosion resistance of specimens before and after hard-facing, considering that in the wood processing process there is wood sap and wood washing water which will have an impact on the equipment due to corrosion, thus affecting the service life of the work equipment, In addition, further research needs to be carried out EDS (Energy Dispersive Spectroscopy) and SEM (Scanning Electron Microscopy) observations to see the hard carbides formed in each hardfacing variation that has been carried out.

REFERENCES

1. Smith, W. F. Structure and Properties of Engineering Alloys, 2nd ed (McGraw-Hill, New York, 1993)
2. P. K. Baghel, Effect of SMAW process parameters on similar and dissimilar metal welds: An overview. *Heliyon*. **8** (2022)
3. S. A. Padhiar, S. Vincent, Effect of hard facing processes on Mild steel A-36 by arc welding. *Materials Today. Proceedings*. **28**, 526-531 (2020). <https://doi.org/10.1016/j.matpr.2019.12.213>
4. A. Gualco, H. G. Svoboda, E. S. Surian, Study of abrasive wear resistance of Fe-based nanostructured hardfacing. *Wear*. **360-361** (2016)
5. R. Suraj, Hardfacing and its effect on wear and corrosion performance of various ferrous welded mild steels. *Materials Today. Proceedings*. **42**, 842- 850 (2021).
6. H. Durmus, et al. Wear performance of Fe-Cr-CB hardfacing coatings: Dry sand/rubber wheel test and ball-on-disc test. *International Journal of Refractory Metals & Hard Materials*. **77**, 37-43 (2018)
7. K. K. Singh, K. A. Anand, V. Kumar. Wear prevention & control as a preventive maintenance strategy. *Materials Today. Proceedings*. **66**, 3949- 3954 (2022)
8. K. Kishore, K. Sarkar, K. S. Arora. Effect of alloying elements on microstructure, wear, and corrosion behavior of Fe-based hardfacing. *Welding in the World*. **67**, 2463-2475 (2023)
9. Gramajo J, A. Gualco, H. Svoboda. Study of the welding procedure in nanostructured super-hard Fe- (Cr, Mo, W)-(C, B) hardfacing. *International Journal of Refractory Metals and Hard Materials*. **88**, 105178 (2020)
10. A. Nazarko, R. Plomodyalo. Influence of chemical composition of wear-resistant hardfacing materials on the tendency to formation of hot cracks during weld facing. *Materials Today. Proceedings*. **19**, 2422-2424 (2019)
11. P. F. Mendez, et al. Welding processes for wear resistant overlays. *Journal of Manufacturing Processes*. **16**, 4-25 (2014)
12. C. Tippayasam, et al. Effects of flux-cored arc welding technology on microstructure and wear resistance of Fe-Cr-C hardfacing alloy. *Materials Today Communications*. **35**, 105569 (2023)

13. W. Guo, et al. Comparison of laser welds in thick section S700 high-strength steel manufactured in flat (1G) and horizontal (2G) positions. *CIRP Annals Manufacturing Technology*. **64**, 197-200 (2015)
14. G. K. Mohanta, A. K. Senapati. The effect of welding parameters on mild steel by MMAW. *ICAEFM*. **410**, 012015 (2018)
15. N. G. Chaidemenopoulos, et al. Aspects on carbides transformations of Fe-based hardfacing deposits. *Surface and Coatings Technology*. **357**, 651-661 (2019)
16. <https://mewelding.com/welding-processes/shielded-metal-arc-welding/>
17. <https://www.mitutoyo.co.id>

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

