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Flash welding of nonalloyed welding wire steel

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1. Introduction

Flash welding was invented in the 1930 s and it is one of the resistance welding processes. The flash welding process is currently used in industry in different applications, such as manufacturing of car wheel rims, because it is a low-cost and cost-effective process [1-3].

The flashing time, voltage and upsetting force and volume have a direct impact on the joint quality. When the voltage is too low or the time abutting surfaces are not plastified enough, the result is a poor quality joint due to insufficient upsetting. If the flashing time is too long, the abutting surfaces will overheat and maintaining a suitable upsetting force will be difficult. When the upsetting force is excessive, too much molten metal is extruded from the joint with insufficient force. Consequently, the joint will be rejected because of its poor quality [3-7].

In endless rolling, flash welding is used to join reheated billets together. Joining billets together in the first stage of the rolling increases productivity while decreasing material consumption during rolling. Flash welding also makes it possible to cut coils according to customers' orders. During rolling, the flash welded joint elongates the three-dimensional parabola opening in the rolling direction, and in some cases the high reduction joint can reach over 10 meters [8].

Ovako Wire Oy Ab in Dalsbruk, Finland, manufactures wire rods with an endless rolling technology (ERT) because its productivity and flexibility enables large and flexible coils sizes. With this system, disturbances, cobbles and wearing of the rolls and guides is reduced and the quality of the wire rod is better and more uniform. An earlier method aiming to increase the weight of the coil resulted in increasing the length or the cross section of the billets. At present, flash butt welded billets are rolled continuously in an automated process. One of the advantages of ERT is flexible production with a larger production volume [8, 9].

Flash welded joints can be investigated through welding tests with different parameters and by adapting destructive testing in accordance with welding procedure testing. The test results enable optimizing the welding parameters and specially the flashing time for the tested material and thickness. The flash weldability ratio according to the cross-section size of the tested billets indicates poor weldability. Therefore, the optimization of the welding parameters is very important. The alloying elements in nonalloyed steel are not exposed to hot cracking, which allows studying the flash welded joint from the flash welding perspective.

2. Experimental procedure

The material used in this research was common nonalloyed welding wire steel 11MnSi6. Its standardized chemical composition (SFS-EN 440) is presented in Table, where single values are maximum values. The tested material measurements for the butt joint were 115*115 mm (4½*4½ in.).

Table
Standardized chemical composition of welding wire steel 11 MnSi6 [%]

C	Si	Mn	P
0.06…0.14	0.70…1.00	1.30…1.60	0.025

S	Ni	Mo	Al	Ti+Zr
0.025	0.15	0.15	0.02	0.02

Joining tests for the welding wire steel with different flashing times were carried out in Dalsbruk, Finland, in their production line between the actual production runs. In consequence, the number of test welds was limited. Eight test welds (A-H) were made with five different flashing times. The upsetting lengths were adjusted to each experimental flashing time. The upper and lower surfaces from the original billets were not recognizable from the test pieces because the test welds were cut of from the line after deburring and two stands.

The test billets were reheated up to 900°C (1652°F) before welding according to wire rod manufacturing. In Dalsbruk, the welding takes place after five passes and oxygen cutting of billet ends. The test welding were performed following the same procedure as actual production. The test pieces are comparable with the actual production until the stage after deburring and two stands. The results in this article are not comparable with an actual wire rod; because of the testing procedure the test pieces are not rolled in a controlled way. The flashing times applied here are readjusted from optimal flashing times. The test welds (A-H) were cut from the rolling mill after the first stand and left to cool down on their own. The cooling of the joints was not controlled.

The test parts were investigated by conducting the following tests: tensile, impact and bending. Also the micro and macro structures of the weld were photographed and the hardness from the weld towards the base metal was measured. The weld was very difficult to localize because austenizing before the flash welding resulted in an almost unnoticeable white weld line. The weld lines in the test pieces could be localized after sawing into the smaller pieces for destructive testing. When preparing the destructive testing pieces the weld line was impossible to localize. After grinding and etching the micro section the weld line became visible.

Due to the limited number of test welds, the test pieces had to be cut in order to complete different destructive tests. Each test weld was cut into two bending and tensile testing pieces. The test specimens for destructive testing were detached symmetrically from every test part. The cutting is depicted in Fig. 1, which also indicates the places of different destructive testing pieces. The cross-section measurements of the tensile test pieces were 8*25 mm (2/6*1 in.). The bending test pieces were left in their maximum width after cutting. The thickness of the test pieces was 10 mm (2/5 in.). Only rough edges were straightened. The bending tests were completed with a press of a diameter of 30 mm (1 1/5 in.). This made the bending harder, and the difference between a good and a poor weld was clear.

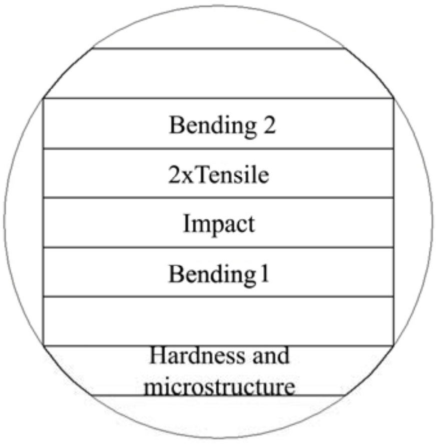

Fig. 1 The cross-section of the test weld and how it is cut

There were two series of impact test pieces from every test weld. The cuts in the impact test pieces were applied directly to the weld line and then moved 2 mm (2/25 in.) and 10 mm (2/5 in.) further towards the base metal. In every series there was one base metal test piece.

3. Results and discussion

The actual width of the weld was determined from the micrograph where the weld had a lighter line compared to the base metal. The weld can be seen vertically in the middle of Fig. 2 where the structure is ferrite and pearlite. The weld had a lighter color compared to the base metal. The structure of the weld, however, had no difference compared to the base metal. The structure in the both cases was equated because of the recrystallization during rolling.

The hardness distributions in the test welds are presented in Fig. 3 where the readjusted flashing times are depicted after the part identifiers. Generally, the hardness in the weld line does not diminish compared to the base metal. The hardness in the weld line is only 10 to 20 HV lower than the base metal hardness, which is approximately 155 HV.

The joint of good quality according to the destructive testing had as great an elongation (35 %) in the case of failure as the base metal, as you can see in Fig. 4 where the elongations are compared to the flashing time. The poorest joint only had an elongation of less than 10 % when failing, and they failed at the weld. In the tensile testing results, the optimal flashing time was very visible with an over 30 % elongation. The differences within the test pieces in elongation may indicate plasticity differences at the abutting surfaces before upsetting. In the tensile test, the curve of the weld after two passes can be one factor influencing the test results. For thick materials, equal plasticity at the surface is very crucial because the distance for the plastic material extruded is longer from the central parts of the joint than for thinner materials. The parallel between the abutting surfaces seems to be emphasized with excessively short or long flashing times.

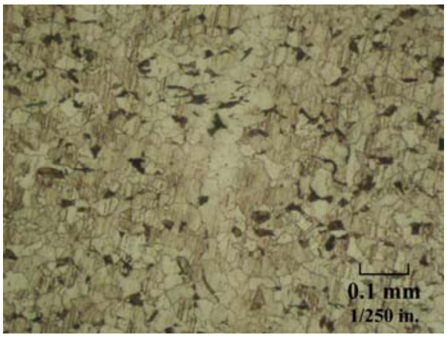

Fig. 2 Micrograph from a flash welded joint

The curve of the weld line was also a factor in the bending test. When setting the bending test piece under the press, the curve had to be taken into consideration. The place of the press compared to the weld line had to be a compromise because of the curve weld line. Therefore, the weld line could not be bent entirely. When exposing the joints to the bending force, there was a notable difference between the strongest and the poorest joints. The results are shown in Fig. 5, where the bending angles are compared to the flashing times. The maximum bending angle is approximately 150° because of the limitations in the test machine. The strongest joints lasted for the entire bending test with only a few very small cracks which did not exceed 2 mm (2/25 in.). For the poorest joints, the bending had to be stopped at the beginning when the bending angle was only a few degrees because large cracks developed in the joints. Moreover, one bending test piece with a flashing time 2 s over the optimal flashing time lasted until the end without failing. That might indicate plasticity differences in the abutting surfaces before upsetting.

An examination of the impact test results revealed large and inconsistent divergences in the impact strength in the specimens where the cut had been made directly into the joint. The impact strength values had no reasonable connection to the flashing times. The best values from the joint corresponded to the impact strength of the base metal, which was approximately 200 J. The impact strength of the poorest joint was under 50 J. When moving the cut further towards the base metal, the divergence in the impact strength diminished and the average impact strength increased nearer to the base metal impact strength values.

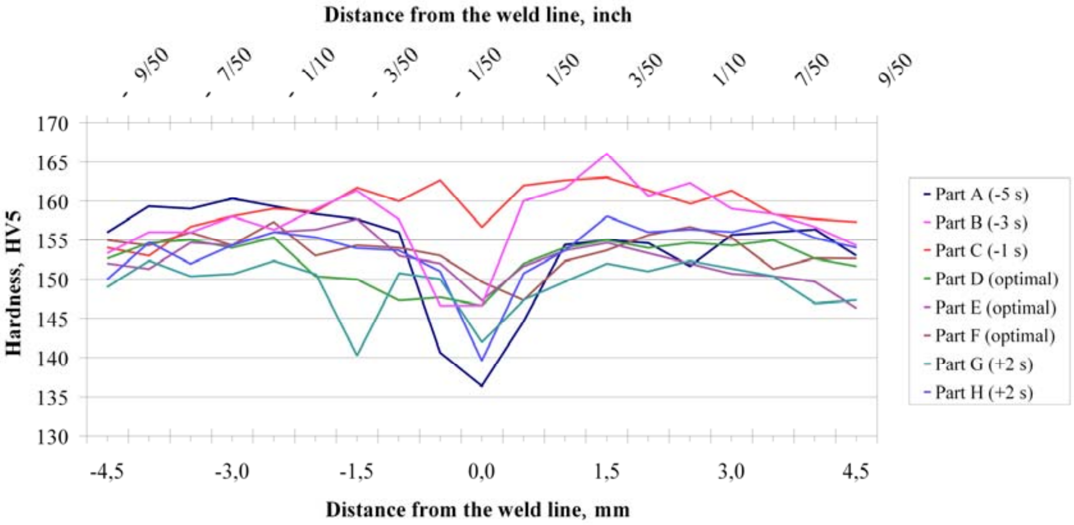

Fig. 3 Hardness distribution in the test welds

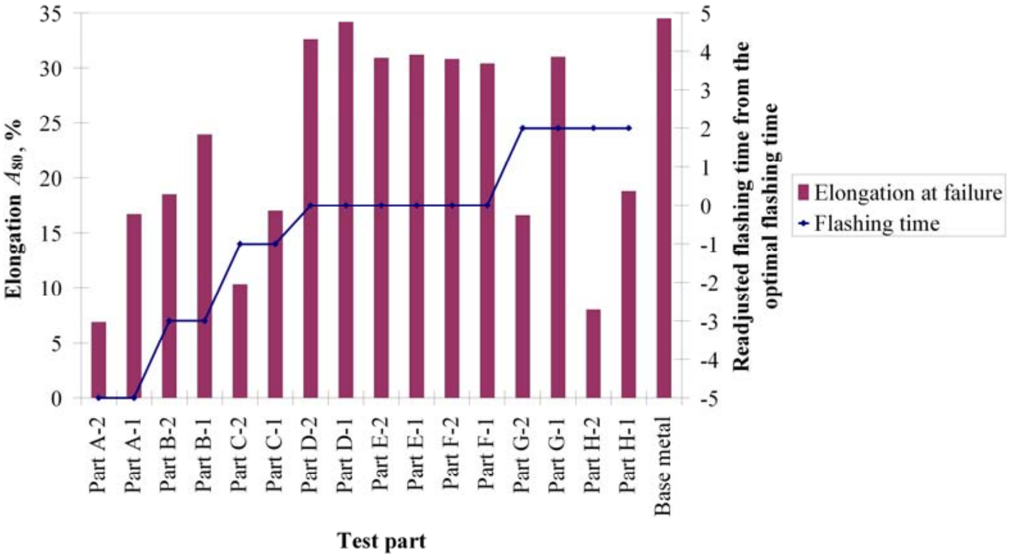

Fig. 4 Elongation at failure in tensile testing

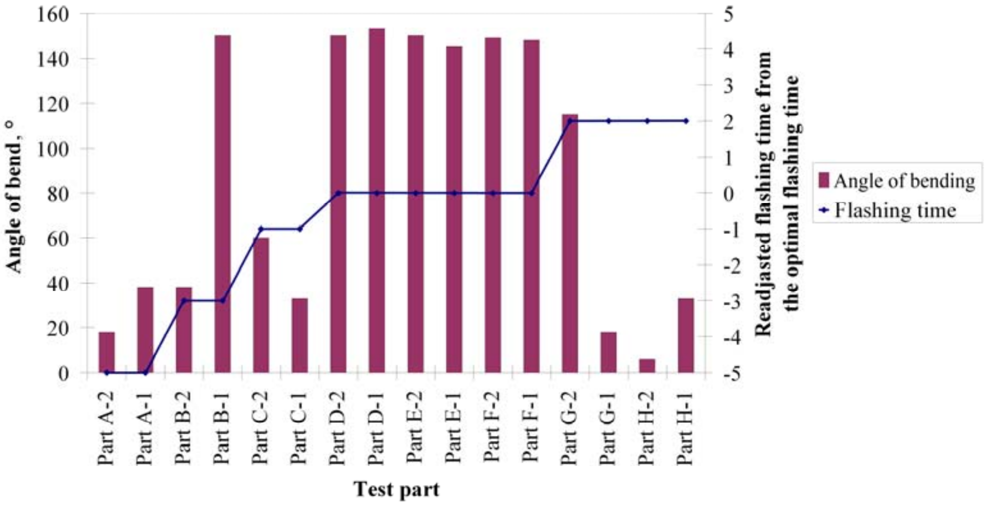

Fig. 5 Bending test results from the test pieces

The divergence in the values from the weld line and the areas near the weld can be explained by the indistinguishable and narrow weld and by the fact that the weld line was not straight after two passes. It is possible that the cuts which were made directly into the joint were not exactly in the joint because of the weld's specific features. Because of the curvature of the weld, the placement of the cut had to be a compromise, which affects the results depending on how curved the weld line is in that impact test piece.

4. Conclusions

The lighter color of the weld line and the hardness distribution over the weld line indicates some differences between the base metal and the weld caused by the flash welding. The difference from the viewpoint of mechanical properties does not have any influence when the flashing time, other welding parameters and pre-welding actions are correct.

The optimal flashing time was defined for the nonalloyed welding wire steel according to these tensile and bending test results. These results also proved how crucial the correct flashing time is in flash welding. The optimal flashing time allows for the needed plasticity in straight and parallel abutting surfaces so that a high-quality flash welded joint can be formed during upsetting. According to the destructive testing results, the quality of the flash welded joint deteriorated even when the flashing time was just one second short of the optimal flashing time. Also, a prolonged flashing time had the same effect on the joint quality. This is due to the fact that too short flashing time cannot plastify the abutting surfaces sufficiently before upsetting, and too long flashing time leads to difficulties in maintaining the correct upsetting force due to excessively plastic metal on the abutting surfaces.

According to the destructive testing results, the properties of flash welded joints after high preheating are equal or almost equal to the properties of the base metal. The hardness of the joint is only 10 to 20 HV lower than the base metal hardness, and the elongation and maximum bending angle are convergent with the base metal. An examination of the impact test results indicates a significant divergence in the properties of the flash welded joint. In this case, the appropriate placement of the cut was very difficult to establish because of the austenizing before welding, leading to the absence of any white line which is typical in flash welding of cold steels. Especially in this case, where the weld is curved after two passes, the placement of the cut was difficult to determine. The curvature of the weld affected the test results because the cuts were not parallel to the weld line. The fact that the width of the weld was narrower than the cut that had to be made and the curve of the weld line made the results unreliable.

The flash welding of thick materials, the straightness and alignment of the abutting surfaces and the appropriate flashing time are emphasised. If the surfaces are not straight and parallel, the plasticity in some parts of the joint seams will not to be an optimal and the weld in those parts will corresponds to welds too a short flashing time.

These experimental test results have allowed improving the control of the process, and consequently, decreasing disturbances. Understanding the importance of pre-welding measures, especially the condition of the billet ends after torch cutting, were major factors in need of improvement in the process.

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NELEGIRUOTO PLIENO VIELOS GALINIŲ PAVIRŠIŲ VIRINIMAS APLYDYMU

Reziumė

Svarbiausi tokio virinimo parametrai aplydomosios siūlės susidarymo trukmė ir elektros srovės įtampa bei vielos galinių paviršių suspaudimo jėga ir dydis. Jei išvardinti parametrai yra aukšti, tai sujungimo paviršiai tampa labai plastiški ir tinkamai suderinti suspaudimo jėgą yra sunku. Jei minėti parametrai yra žemi, tai virimo metu nesusidaro pakankamas sujungtų paviršių plastiškumas ir tokiu būdu gaunamas netinkamas jungiamų paviršių apspaudimas prieš virinimą. Aplydomosios siūlės kokybė taip pat būna nepakankama jungiamojo ploto dydžiu; tai rodo virinimo parametrų optimizavimo būtinybę, siekiant aplydomosios siūlės aukštos kokybės virinimo metu.

Kalibruotos vielos ritinių gamyboje nesibaigiantis valcavimo procesas galėtų pagerinti gamybos našumą ir lankstumą. Šie parametrai gali būti gerinami judančiąja aplydomosios siūlės virinimo sistema, kuri naudojama sujungti įkaitintiems vielos gamybos ruošiniams prieš valcavimą. Kadangi aplydomosios siūlės virinimo procesui kokybė yra ypač svarbi, tai straipsnyje atlikti tyrimai skirti virinimo laiko ir proceso kokybės santykiui nustatyti.

Aplydomosios siūlės bandinių medžiagos struktūra ir charakteristikos esant skirtingam virinimo laikui nustatytos irimo bandymais. Virinimo proceso bandymų rezultatai parodė, jog ne visi bandiniai atitiko kokybės reikalavimus.

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FLASH WELDING OF NONALLOYED WELDING WIRE STEEL

Summary

The most important welding parameters are flashing time and voltage as well as upsetting force and volume. If the parameters are too high, the joint surfaces become too plastic and maintaining a suitable upsetting force is difficult. If the parameters are too low, the plastifying effect on the joint surfaces is left unfinished and upsetting remains insufficient. The quality of flash welded joints is also influenced by the size of the joint area, which means optimization of the parameters is necessary for a high-quality flash welded joint.

In the manufacture of wire rod coils, the endless rolling process can improve the productivity and flexibility of production. These properties are based on the moving flash welding system which is used to join reheated billets together before rolling. Since the quality of the flash welded joints is of essential importance for the manufacturing process, this research investigated the effects of the flashing time on the quality of the joint made by welding wire steel.

The structure and characteristics of the test pieces welded with different flashing times were investigated with destructive testing. On the basis of the welding procedure tests the joints of some test welds did not completely meet the quality requirements.

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СТЫКОВАЯ СВАРКА ОПЛАВЛЕНИЕМ ПРОВОЛОКИ ИЗ НЕЛЕГИРОВАННОЙ СТАЛИ

Резюме

В публикации обсуждаются основные параметры стыковой сварки оплавлением: напряжение электрического тока и сила сжатия концевых поверхностей проволок. Если перечисленные параметры очень большие, сваренные поверхности становятся чрезмерно пластические и правильно урегулировать силу высадки на установке становится очень трудно. Если эти параметры очень низкие, эффект пластичности становится недостаточным и следовательно получается недостаточная высадка поверхностей во время сварки. Качество стыковой сварки оплавлением также зависит от величины поверхности стыковки, что вызывает необходимость оптимизировать выше указанные параметры для получения высокого качества сварки.

Производство рулонов проволочной спирали непрерывным прокатным методом может повысить производительность и гибкость производства. Процесс основан на передвижной системе стыковой сварки для соединения заново нагретых заготовок перед процессом катания. Так как качество стыкового соединения является особенно важной для производственного процесса, поэтому в статье исследовано влияние времени сварки на его качество.

Образцы изготовленные для различного времени сварки были исследованы методом разрушения для получения структуры и пластичности стали. Результаты исследования показали, что не все образцы соответствовали требованиям качества.

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