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PREDICTION THE EFFECT OF FLAME CUTTING PARAMETERS ON THE QUALITY OF METAL SURFACE IN CNC FLAME CUTTING MACHINE USING ARTIFICIAL NEURAL NETWORK

Dr. Osamah F. Abdulateef ausamalanee@yahoo.com
Dr. Faiz F. Mustafa faizalrawy@yahoo.com
Salah A. Salman Selah_zb@yahoo.com

University of Baghdad, AL-Khwarizmi College of Eng. Manufacturing Process Eng. Dept.

ABSTRACT:

Many metal-manufacturing industries include oxyfuel cutting among their manufacturing processes because cutting and welding are often required in metal-cutting processes, specifically in the fabrication of pressure vessels and storage tanks. The oxyfuel cutting process uses controlled chemical reactions to remove preheated metal by rapid oxidation in a stream of pure oxygen. Previous research has demonstrated that metal cutting surfaces varied depending on the gas used for the combustion as well as the cutting speed (Vc) used during the process. In this research, ASTM BN1323 carbon steel was cut using CNC flame cutting machine. The study constrained on the effect of cutting parameters (cutting speed Vc, Preheat time, and plate thickness) on the quality of the metal surface being cut. The Different tests, such as surface roughness and hardness were used to analyze the influence of these parameters.

. The effect of cutting parameters on the surface quality was studied by implementing the experimental results obtained from cutting a non-Galvanized steel plate ASTM BN 1323 in different cutting parameters (cutting speed, preheat time, and plate thickness) followed by non-destructive (hardness and roughness of a cutting surface) tests to investigate the quality control on the cut specimens. The results showed, in general, better cut surfaces when using the optimum parameters V_c=300 mm/min. and preheat time =20 sec for cutting 20 mm thickness of non–Galvanized steel sheet ASTM BN1323. The experimental results obtained are then processed through the ANN model to control the cutting process and predict the level of quality for different cutting conditions. It has been deduced that the cutting conditions (cutting speed, preheat time, and plate thickness) had a dominant factors that affected the cut quality. Also we found that for certain cutting condition, there was an optimum cutting speed to obtain an optimum cutting quality. The system supports quality control procedures and cutting productivity without doing more periodic destructive mechanical test to dozens of samples.

KEYWORDS:
Artificial Neural Network, Flame cutting, oxy-fuel process.

الأستقصاء عن تأثير عوامل القطع بأللهب على نوعية السطح المعدني في ماكنة اللهب المؤتمته بأستخدام الشبكة العصبية الإصطناعية

أ.م.د. أسامة فاضل عبداللطيف
م. د. فائز فوزي مصطفى
م.م صلاح سلمان عبدالكريم
كلية هندسة الخوارزمي/قسم هندسة عمليات التصنيع

الخلاصة

تتضمّن الكثير من القطاعات الصناعية عمليات قطع المعدن بأستخدام الشعلة الأوكسي-أستيلينية خاصة في صناعة السفن وخزانات الضغط. تعتمد عمليات قطع المعدن بأستخدام الشعلة الأوكسي-أستيلينية على التفاعلات الكيمياوية لإزالة المعدن المسخّن بالأكسدة السريعة. بيّن البحوث السابق' بأنّ سطوح المعدن المقطوع تعتمد على عدة عوامل منها نوع الغاز المستعمل و سرعة القطع (Vc) المستخدمة. تم في هذا البحث قطع صفيحة من الفولاذ الكاربوني بإستعمال ماكنة قطع بأللهب مؤتمته. وقد بينت الدراسة تأثيرعوامل القطع (سرعة القطع Vc، زمن التسخين المسبق، وسمك الصفيحة) على نوعية السطح المعدني بعد القطع. تم أستخدام إختبارات الصلادة والخشونة لتحليل تأثير هذه العوامل.

أن دراسة تأثيرعوامل القطع على النوعية السطحيّة تمت بتطبيق النتائج التجريبية التي تم الحصول عليها من قطع صفيحة فولاذ غير مغلون تحت عوامل مختلفة (سرعة قطع، زمن التسخين المسبق، وسمك الصفيحة) تلتها أجراء فحوصات لاتدميرية (صلادة وخشونة سطح القطع) لتحرّي مراقبة الجودة على نماذج القطع. النتائج بينت بشكل عام أن أفضل قطع عند إستعمال سرعة قطع 300 مليمتر /دقيقة وزمن تسخين 20 ثانية لقطع صفيحة سمكها 20 مليمتر من الفولاذ غير المغلون. تم معالجة النتائج العملية المكتسبة من خلال نموذج لشبكة عصبية أصطناعية لغرض دعم إجراءات مراقبة الجودة ومعدل الإنتاج للقطع بدون عمل إختبار ميكانيكي تدميري للعشرات من العينات.

INTRODUCTION:

Before discovery of acetylene, metals were cut and welded by using oxy- hydrogen cutting process. In 1892 Major J. Turner Morehead and Thomas Wilson discovered acetylene which burned with great brilliancy. Oxy fuel cutting is thermal and chemical cutting process .Hence no tool wear takes place and also cutting forces generated are very much negligible. Moreover it uses lightweight fixtures which are very cost effective and consuming less time.

CNC Flame Cutting provides a very efficient and accurate method for preparing component shapes prior to fabricating a part. Individual component drawings are first imported into nesting software to generate an optimum layout on the available raw material. Once the cutting plan is finalized, the layout is transferred to the CNC Flame Cutting machine which will rapidly cut all the individual parts from the loaded plate using a completely automated Oxy/Fuel flame cutting head. Cutting and machining allowances as well as single bevels if any may be specified ahead of time. Dimensional accuracy as well as cut surface finish is far superior to manual methods and this directly translates to fast fabrication and machining.

The oxyfuel process is the most widely applied industrial thermal cutting process because it can cut thicknesses from 0.5mm to 250mm, the equipment is low cost and can be used manually or mechanized. There are several fuel gas and nozzle design options that can significantly enhance performance in terms of cut quality and cutting speed [1].

CUTTING PROCESS:

The cutting process is illustrated in Fig. 1. Basically, a mixture of oxygen and the fuel gas is used to preheat the metal to its 'ignition' temperature which, for steel, is 700°C - 900°C (bright red heat) but well below its melting point. A jet of pure oxygen is then directed into the preheated area instigating a vigorous exothermic chemical reaction between the oxygen and the metal to form iron oxide or slag. The oxygen jet blows away the slag enabling the jet to pierce through the material and continue to cut through the material. There are four basic requirements for oxy-fuel cutting [2,3]:

1- The ignition temperature of the material must be lower than its melting point otherwise the material would melt and flow away before cutting could take place.

2- The oxide melting point must be lower than that of the surrounding material so that it can be mechanically blown away by the oxygen jet.
3- The oxidation reaction between the oxygen jet and the metal must be sufficient to maintain the ignition temperature.
4- A minimum of gaseous reaction products should be produced so as not to dilute the cutting oxygen.

As stainless steel, cast iron and non-ferrous metals form refractory oxides ie the oxide melting point is higher than the material, powder must be injected into the flame to form a low melting point, fluid slag.

Purity of oxygen

The cutting speed and cut edge quality are primarily determined by the purity of the oxygen stream. Thus, nozzle design plays a significant role in protecting the oxygen stream from air entrainment. The purity of oxygen should be at least 99.5%. A decrease in purity of 1% will typically reduce the cutting speed by 25% and increase the gas consumption by 25%.

Choice of fuel gas

Fuel gas combustion occurs in two distinct zones. In the inner cone or primary flame, the fuel gas combines with oxygen to form carbon monoxide and hydrogen which for acetylene, the reaction is given by:

$2C_2H_2 + 2O_2 \rightarrow 4CO + 2H_2$

Combustion also continues in the secondary or outer zone of the flame with oxygen being supplied from the air.

$4CO+2H_2+3O_2 \rightarrow 4CO_2+2H_2O$

Thus, fuel gases are characterized by:

1- Flame temperature - the hottest part of the flame is at the tip of the primary flame (inner cone).
2- Fuel gas to oxygen ratio - the amount of fuel gas required for combustion but this will vary according to whether the flame is neutral, oxidizing or reducing.
3- Heat of combustion - heat of combustion is greater in the outer part of the flame.

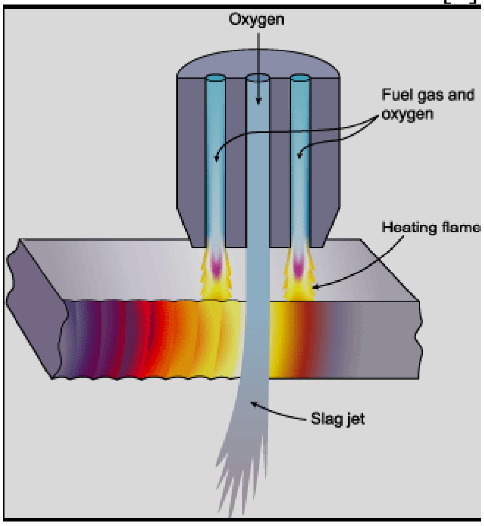
The five most commonly used fuel gases are acetylene, propane, MAPP (methylacetylene-propadiene), propylene and natural gas. The properties of the gases are given in the Table 1. The relative performance of the fuel gases in terms of pierce time, cutting speed and cut edge quality, is determined by the flame temperature and heat distribution within the inner and out flame cones.

Table (1): Fuel gas characteristics

Fuel Gas	**Maximum Flame Temperature °C**	**Oxygen to fuel gas Ratio (vol)**	**Heat distribution kJ/m3**	
			Primary	Secondary
Acetylene	3,160	1.2:1	18,890	35,882
Propane	2,810	4.3:1	10,433	85,325
MAPP	2,927	3.3:1	15,445	56,431
Propylene	2,872	3.7:1	16,000	72,000

Hydrogen	2,834	0.42:1	-	-
Natural Gas	2,770	1.8:1	1,490	35,770

The cutting process is illustrated in Fig. 1 given below. A mixture of oxygen and the fuel gas is used to preheat the metal to its ignition temperature (bright red heat) but well below its melting point. A jet of pure oxygen is then directed into the preheated area. This triggers a vigorous exothermic chemical reaction between the oxygen and the metal to form Iron Oxide or slag. The oxygen jet blows away the slag enabling the jet to pierce through the material and continue to cut the material [4].



Fig(1): Sectional view of oxyacetylene cutting process

EFFECT OF CUTTING PARAMETERS ON QUALITY OF CUT:

The quality of cut depends mainly on parameters like cutting speed, oxygen pressure, type of nozzle selected.

A. Cutting Speed

The increase in cutting speed decreases the quality of the cut resulting in rounding of the bottom edge to some extent and also undercuts the edge which destroys the flatness. Also the slow speed results in unstable operation which causes gauges in the face of the cut. [5].

B. Oxygen Pressure

As the oxygen pressure goes up, the diameter of the stream increases comparatively faster than the increase in oxygen flow. This increases the width of cut and provides less oxygen to oxidize the steel which results in loss of quality. Also when oxygen pressure is less the gauging takes place and slag will not be removed from the surface of the metal. [6].

C. Nozzle

The use of oversized nozzles produces a cut that has considerable ‘cut face’ angle. The oversized oxygen stream expands as it passes through the plate. This results in the bottom of the cut being wider than the top. Increase in speed can reduce the cut width and face angle but at the cost of quality of surface. Smaller nozzles can be used to cut heavier thickness with dramatic reductions in speed with comparatively good quality [6].

EXPERIMENTAL SETUP:

In oxy acetylene cutting process cutting torch is not the “cutting tool”. It only supplies homogeneous mixture of oxygen and acetylene to produce a flame. Since there is no contact between cutting torch and metal very small cutting forces are generated which is the very basis for the design of assembly. The details of experimental set up, instrumentation and the procedure of working operation are listed below:

1- Select a non–Galvanized steel sheet ASTM BN1323 with different thickness having mechanical properties shown in Table 2. We fixed sheets by a suitable devise in the horizontal level, prior to the cutting process.

Table (2): Mechanical properties for the base metal represented in mechanical tests

Mechanical test type	**Hardness test HV**	**Tensile strength N/m^2**	**Bending stress N/m^2**
Mechanical test value	122	27.916	749.57

2- Using SATO CNC flame cutting machine to perform thermal cutting process. This machine has manual and NC operating modes. NC mode was used to fix the cutting parameters (holing time=5sec, preheat pressure=50psi, cutting pressure=80psi, torch distance=10mm). This CNC machine is very accurate and precise machine and used for cutting ferrous alloys and can cut thickness up to 130 mm. Fig. 2 shows SATO CNC flame cutting machine.
3- Select different cutting conditions for each case (cutting travel speed, preheating time) as shown in Table 3.
4- The work piece must be cooled naturally after cutting.
5- Non-destructive (roughness and hardness test) were performed to check cutting surface.
6- Metallurgical test was performed to determine the grain structure in the base metal and cutting surface.

Fig (2): SATO CNC flame cutting machine

A. Surface roughness tester

Digital Surface roughness tester is used for measuring surface roughness for all specimens in order to investigate the effects of cutting parameter on the surface integrity. The tester is leveled and calibrated using standard block test before carrying out the test. Three readings were taken for each specimens and the average is recorded. Fig. 3 shows the digital roughness tester.

Fig (3): Digital surface roughness tester

B. Rockwell hardness tester

Rockwell hardness tester scale B was used to measure the hardness of the four specimens as described below:

1-The specimen is put on suitable anvil.

2-The minor load is applied using hand wheel to touch the specimen with ball indenter until the pointer be on the stet point.

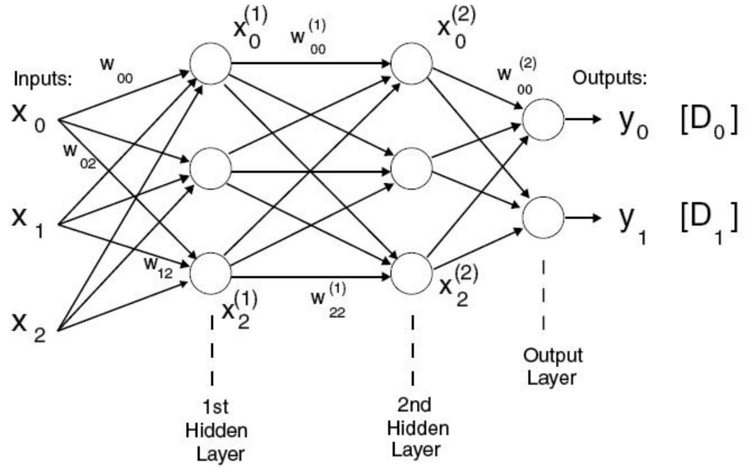
3-The major load (100 Kgf) is applied by release the arm in the side and waits for 15 seconds to steady the load.

4-The load is released and the reading is taken directly from the dial.

FLAME CUTTING MONITORING USING NEURAL NETWORKS:

To develop a neural-network model, input and output parameters of the component should be identified in order to generate and preprocess data, and then use this data to carry out ANN training. For the purpose of performing reliable processing to the results obtained in this research, a neural network has been established to develop ANN model utilizing quality parameters (surface roughness and hardness of cutting surface).

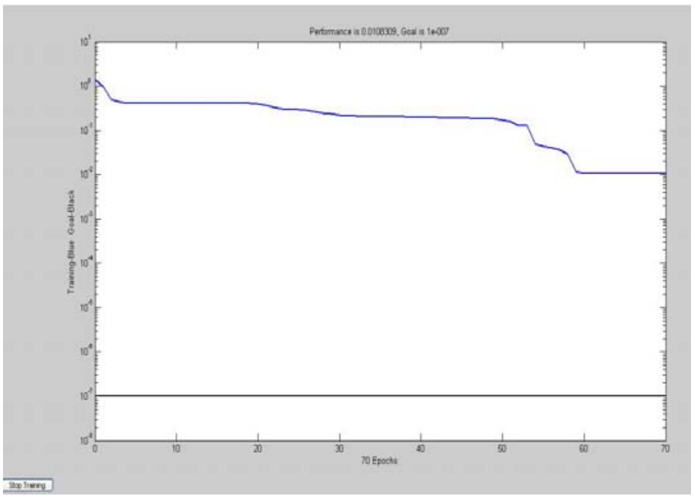
The first step toward developing a neural model is the identification of inputs and outputs. Determination of output parameters are based on the purpose of the neural-network model. The input output variables, number of nodes and activation functions are shown in Fig. 4, in which the input variables are cutting travel speed, preheat time, and plate thickness therefore a number of input nodes is set to 3. Output variables are surface roughness and hardness, therefore a number of output nodes is set to 2. There are two hidden layers and the number of nodes is set to 5 and 3. Log-Sigmoid is used as activation functions for hidden layer No.1 and 2 and pure line function for output layer. Levenberg - Marquardt (LM) is used as a training method, where ten experimental sets are taken as training data [7]. Eventually, creating ANN programs by MATLAB (V7) [8].



Fig(4): A Feed Forward Artificial Neural Network model utilizing quality parameters (cutting speed, preheat time, and plate thickness) [9]

RESULTS AND DISCUSSIONS:

ANN was developed utilizing quality parameter (cutting speed – preheat time – plate thickness). Making use of experimental result data (surface roughness, surface hardness) has been trained a neural network for a process model which can predict the level of quality for different cutting conditions as shown in Table 3. The training curve of the network is shown in Fig. 5. Running the network gives an important advantage showing its ability to predict additional readings of quality parameter beside the original ones obtained from the experimental work upon inserting new interface values of cutting conditions taken within the employed ranges, it will be noticed that the network also predicts new interface reading of quality parameter (hardness and roughness) approaching the values to those obtained from the experimental runs.



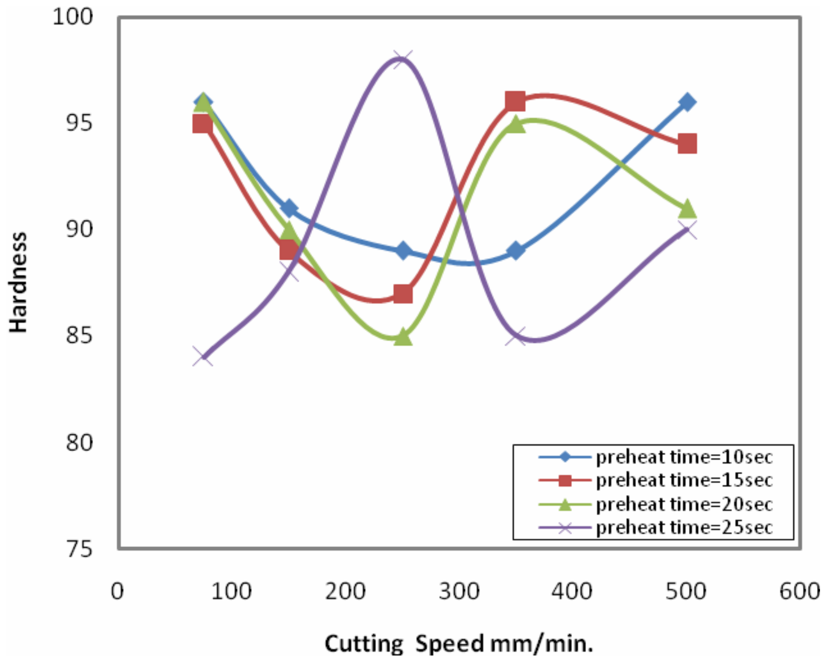
Fig(5): ANN training curve utilizing quality parameters

Table (3): ANN output utilizing quality parameters (Hardness and Roughness of cutting surface

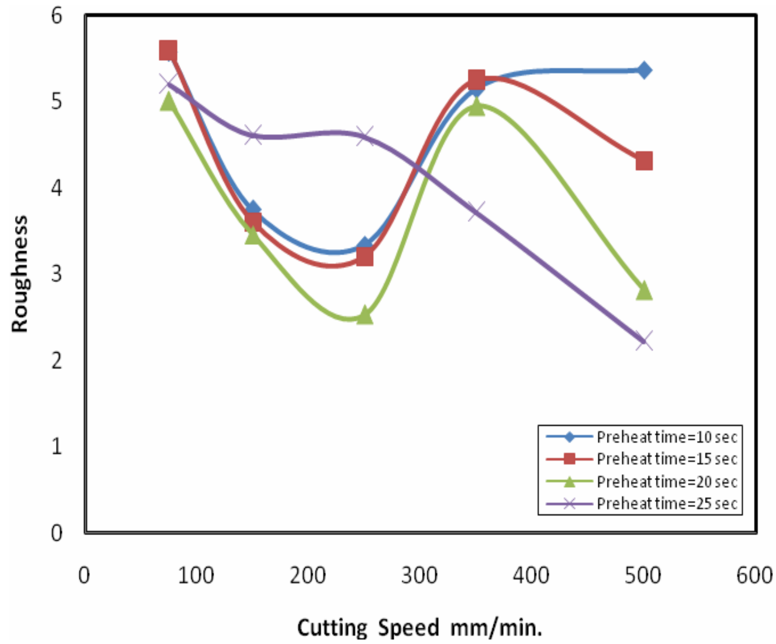
Input No.	**Plate thickness (mm)**	**Cutting speed (mm/min)**	**Preheat time (sec)**	**Hardness of cutting surface (HRc)**	**Roughness of cutting surface (Ra)**
1	20	75	10	96	5.58
2	20	150	10	91	3.75
3	20	250	10	89	3.34
4	20	350	10	89	5.15
5	20	500	10	96	5.37
6	20	75	15	95	5.59
7	20	150	15	89	3.61
8	20	250	15	87	3.21
9	20	350	15	96	5.25
10	20	500	15	94	4.32
11	20	75	20	96	5.01
12	20	150	20	90	3.46
13	20	250	20	85	2.53
14	20	350	20	95	4.95
15	20	500	20	91	2.82
16	20	75	25	84	5.2
17	20	150	25	88	4.61
18	20	250	25	98	4.59
19	20	350	25	85	3.72
20	20	500	25	90	2.219
21	15	75	20	87	3.67
22	15	150	20	85	2.021
23	15	250	20	87	2.306
24	15	350	20	95	3.011
25	15	500	20	89	6.49
26	12.5	75	15	88	2.922
27	12.5	150	15	92	3.2
28	12.5	250	15	86	3.436
29	12.5	350	15	87	4.6
30	12.5	500	15	88	5.053
31	10	75	10	86	2.07
32	10	150	10	96	2.045
33	10	250	10	85	2.015
34	10	350	10	96	3.589
35	10	500	10	94	2.86

Cutting conditions and quality parameters is a name of neural networks which have been trained to a set of data derived from the practical experimental runs, made the networks ready to receive new data for subsequent prediction. New data should be accordingly set as input parameters, which represents only the cutting conditions within the limits adopted in this study. Consequent outputs are new rates that represent only quality parameters which are predicted by the pre-trained neural networks. It is so clear that agreement of the total values and convergence readings of each set to the other shows that the trained neural networks are ready to predict quality parameters whenever it is required. Some networks results were found far from reasonable values due to inadequate neural network training data, because of the limited number of samples and need for modern instrument to reduce the time of testing samples.

The experimental work on flame cutting had shown several practical variables and it gave clear indications for cutting quality precept and resulting mechanical properties. These variables are: Hardness and roughness test reading of cutting surface. Quality monitors and control processes have been implemented by adopting variable cutting conditions in order to know the result of changing these conditions on cutting surface quality. Flame cutting conditions include: cutting speed, preheat time, and plate thickness. Fig. 6 and 7 shows the relationship between cutting speed and mechanical properties of a cutting surface (hardness and roughness of the cutting surface) at different preheat times. We can show that the rates of flame cutting quality parameter in general increase with increasing of cutting speed and preheat time to a certain limit after that the increase in speed and preheat time caused decrease of cutting quality parameter because of high temperature produced in cutting process that causes melting of work piece partially or completely at the cutting material.



Fig(6): Variation of hardness with cutting speed (plate thickness=20mm)



Fig(7): Variation of roughness with cutting speed (plate thickness=20mm)

CONCLUSIONS:

The main conclusions of this research are:

- The system supports quality control procedures and flame cutting productivity without the need to stop the production sequence or doing more periodic destructive mechanical testing to dozens of samples. Here, it can be noted which economical gains could be achieved in utilizing such electronic surveillance feature.
- Reduce the probability of flame cutting failure and decide the weakness points and layers after checking the current response and delimitation of the defect region to be tested.
- The optimum parameters achieved (for cutting 20 mm thickness of non–Galvanized steel sheet ASTM BN1323 are V_c=300 mm/min. and preheat time =20 sec.
- ANN was a useful technique to predict the level of quality for different cutting conditions utilizing quality parameters (cutting speed, preheat time) using experimental result data (hardness and roughness of cutting surface). This ANN could predict any surface cutting quality parameter for any cutting conditions within the range of previous input value.

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